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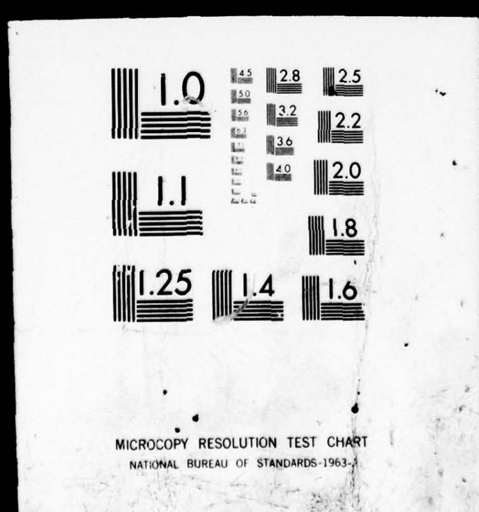

Report No. FAA-RD-79-68

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EXHAUST EMISSIONS CHARACTERISTICS FOR A GENERAL AVIATION LIGHT-AIRCRAFT AVCO LYCOMING TIO–540–J2BD PISTON ENGINE

Eric E. Becker

FINAL REPORT

SEPTEMBER 1979

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16. Abstract

The Avco Lycoming TIO-540-J2BD engine (S/N890-X) was tested at the National Aviation Facilities Experimental Center (NAFEC) to develop a steady state exhaust emissions data base. This data base consists of current production baseline emissions characteristics, lean-out emissions data, effects of leaning-out the fuel schedule on cylinder head temperatures, and data showing ambient effects on exhaust emissions and cylinder head temperatures. The engine operating with its current full-rich production fuel schedule could not meet the proposed Environmental Protection Agency (EPA) standard for carbon monoxide (CO) and unburned hydrocarbons (HC) under sea level standard-day conditions. The engine did, however, meet the proposed EPA standards for oxides of nitrogen (NO_x) under the same sea level conditions. The results show a trend toward higher levels of emissions output for CO and HC when the ambient conditions approximated hot day sea level conditions while producing slightly lower levels of NO_x.

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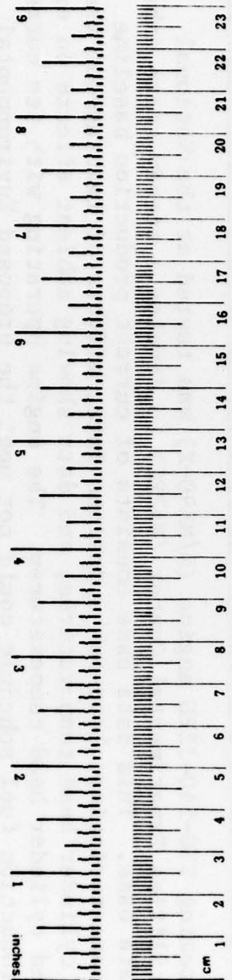
METRIC CONVERSION FACTORS

Approximate Conversions to Metric Measures

Symbol	When You Know	Multiply by	To Find	Symbol
		LENGTH		
in	inches	*2.5	centimeters	cm
ft	feet	30	centimeters	cm
yd	yards	0.9	meters	m
mi	miles	1.6	kilometers	km
		AREA		
in^2	square inches	6.5	square centimeters	cm^2
ft^2	square feet	0.09	square meters	m^2
yd^2	square yards	0.8	square meters	m^2
mi^2	square miles	2.6	square kilometers	km^2
	acres	0.4	hectares	ha
		MASS (weight)		
oz	ounces	28	grams	g
lb	pounds	0.45	kilograms	kg
	short tons (2000 lb)	0.9	tonnes	t
		VOLUME		
tsp	teaspoons	5	milliliters	ml
Tbsp	tablespoons	15	milliliters	ml
fl oz	fluid ounces	30	milliliters	ml
c	cups	0.24	liters	l
pt	pints	0.47	liters	l
qt	quarts	0.95	liters	l
gal	gallons	3.8	liters	l
ft^3	cubic feet	0.03	cubic meters	m^3
yd^3	cubic yards	0.76	cubic meters	m^3
		TEMPERATURE (exact)		
°F	Fahrenheit temperature	5/9 (after subtracting 32)	Celsius temperature	°C

*1 in = 2.54 (exactly). For other exact conversions and more detailed tables, see NBS Misc. Publ. 286, Units of Weights and Measures, Price $2.25, SD Catalog No. C13.10:286.



Approximate Conversions from Metric Measures

Symbol	When You Know	Multiply by	To Find	Symbol
		LENGTH		
mm	millimeters	0.04	inches	in
cm	centimeters	0.4	inches	in
m	meters	3.3	feet	ft
m	meters	1.1	yards	yd
km	kilometers	0.6	miles	mi
		AREA		
cm^2	square centimeters	0.16	square inches	in^2
m^2	square meters	1.2	square yards	yd^2
km^2	square kilometers	0.4	square miles	mi^2
ha	hectares (10,000 m^2)	2.5	acres	
		MASS (weight)		
g	grams	0.035	ounces	oz
kg	kilograms	2.2	pounds	lb
t	tonnes (1000 kg)	1.1	short tons	
		VOLUME		
ml	milliliters	0.03	fluid ounces	fl oz
l	liters	2.1	pints	pt
l	liters	1.06	quarts	qt
l	liters	0.26	gallons	gal
m^3	cubic meters	35	cubic feet	ft^3
m^3	cubic meters	1.3	cubic yards	yd^3
		TEMPERATURE (exact)		
°C	Celsius temperature	9/5 (then add 32)	Fahrenheit temperature	°F

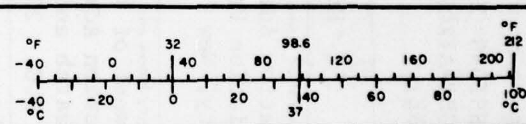


TABLE OF CONTENTS

LIST OF ILLUSTRATIONS

LIST OF ILLUSTRATIONS (Continued)

LIST OF TABLES

INTRODUCTION

PURPOSE.

General aviation piston engine exhaust emission tests were conducted at the National Aviation Facility Experimental Center (NAFEC) for the following reasons:

1. Determine and establish total exhaust emissions characteristics for a representative group of current production general aviation piston engines.

2. Determine the effects of leaning-out of the fuel metering system on exhaust emissions.

3. Verify the acceptability of test procedures, testing techniques, instrumentation, etc.

4. Determine reductions in operating limits and safety margins resulting from fuel system adjustments/modifications evaluated for improved piston engine exhaust emissions characteristics.

BACKGROUND.

Beginning in 1967, Congress enacted a series of laws which added environmental considerations to the civil aviation safety, control, and promotional functions of the Federal Aviation Administration (FAA). This legislation was in response to the growing public concern over environmental degradation. Thus, the FAA was committed to the development, evaluation, and execution of programs designed to identify and minimize the undesirable environmental effects attributable to aviation.

In accordance with the Clean Air Act Amendments of 1970, the Environmental Protection Agency (EPA) established emission standards and outlined test procedures when it used EPA rule part 87 in January 1973. The Secretary of Transportation and, therefore, the FAA was charged with the responsibility for issuing regulations to implement this rule and enforcing these standards.

Implementation of this rule was contingent on the FAA's finding that safety was not impaired by whatever means was employed to achieve the standards. For this reason the FAA undertook a program, subsequent to the issuance of the EPA emission standards in July 1973, to determine the feasibility of implementation, verify test procedures, and validate test results.

There was concern that the actions suggested in order to comply with the EPA emission standards, such as operating engines at leaner mixture settings during landing and takeoff cycles, might compromise safety and/or significantly reduce engine operating margins. Therefore, the FAA contracted with Avco Lycoming and Teledyne Continental Motors to select engines that they considered typical of their production, test these engines as normally produced

to establish a baseline emissions data base, and then alter (by lean-out adjustments) the fuel schedule and ignition timing to demonstrate methods by which the proposed EPA limits could be reached. In the event that hazardous operating conditions were indicated by the manufacturer's tests, independent verification of data would be necessary. Therefore, duplication of the manufacturer's tests was undertaken at NAFEC to provide the needed verification and expand the emissions data base through independent testing.

This report presents the NAFEC test results for the AVCO Lycoming TIO-540-J2BD piston engine (S/N890-X). It should be noted that since the time of these tests, the EPA has rescinded the promulgated piston engine standards (reference 1). This work is reported upon herein in the same light as it would have been if the requirements were still in effect.

DISCUSSION

DESCRIPTION OF AVCO LYCOMING TIO-540-J2BD ENGINE.

The TIO-540-J2BD engine tested at NAFEC is a fuel-injected, horizontally opposed engine with a nominal 540 cubic inch displacement (cid), rated at 350 brake horsepower (bhp) for a nominal brake specific fuel consumption (bsfc) of 0.70. This engine is designed to operate on 100/130 octane aviation gasoline (appendix A--Fuel Sample Analysis of NAFEC Test Fuel). The vital statistics for this engine are provided in table 1.

TABLE 1. AVCO LYCOMING TIO-540-J2BD

No. of Cylinders	6
Cylinder Arrangement	HO
Max. Engine Takeoff Power (HP, RPM)	350,2575
Bore and Stroke (in.)	5.125 x 4.375
Displacement (cu. in.)	541.5
Weight, Dry (lbs)--Basic Engine	518.0
Propeller Drive	Direct
Fuel Grade--Octane Rating	100/130
Compression Ratio	7.3:1
Max. Cylinder Head Temperature Limit (°F)	475

DESCRIPTION OF TEST SET-UP AND BASIC FACILITIES.

For the NAFEC sea level static tests, the engines were installed in the propeller test stand shown in figures 1 and 2. This test stand was located in the NAFEC General Aviation Piston Engine Test Facility. The test facility provided the following capabilities for testing light aircraft piston engines:

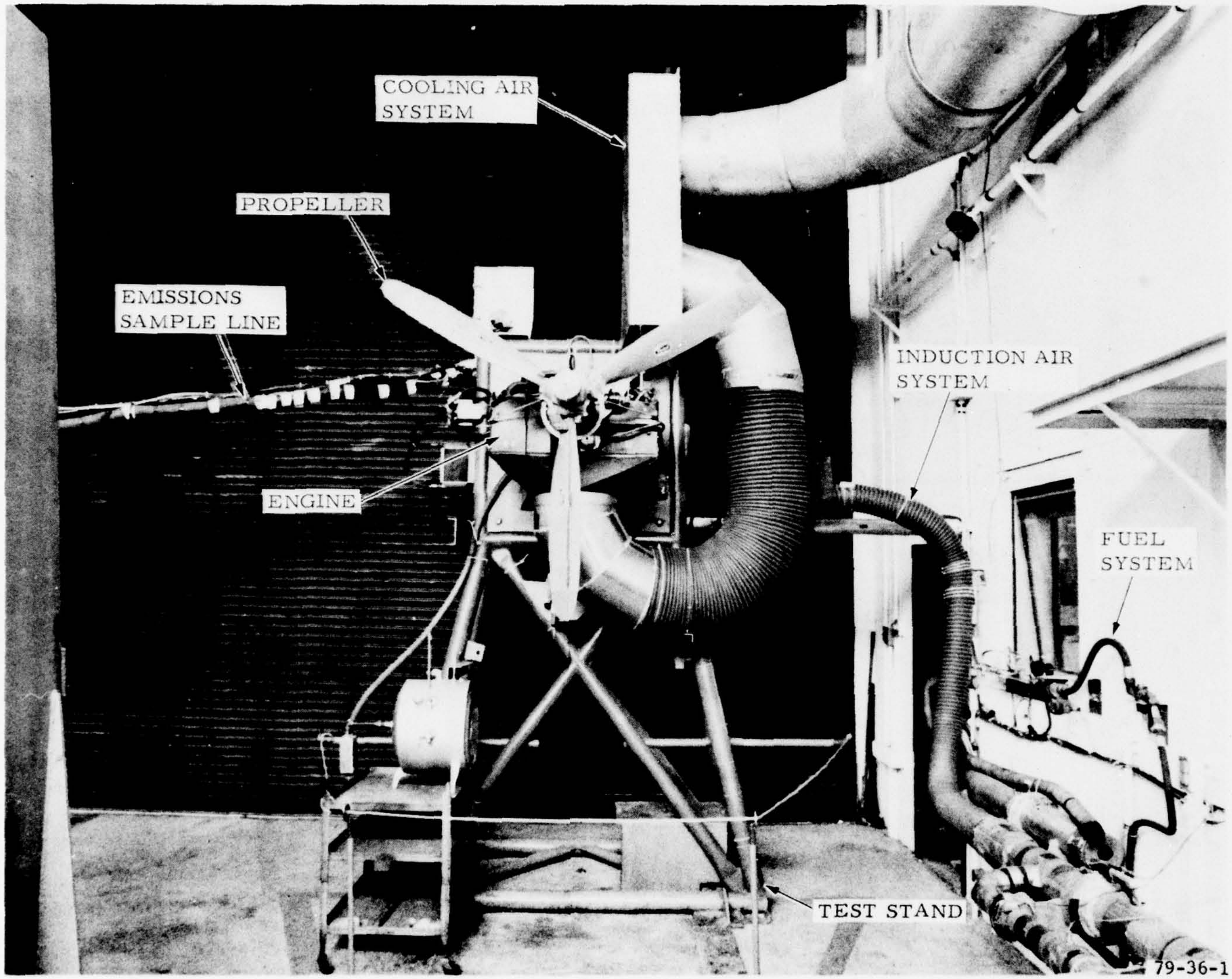


FIGURE 1. SEA LEVEL PROPELLER TEST STAND--AVCO LYCOMING TIO-540-J2BD ENGINE INSTALLATION--EMISSIONS TESTING--VIEW LOOKING AFT

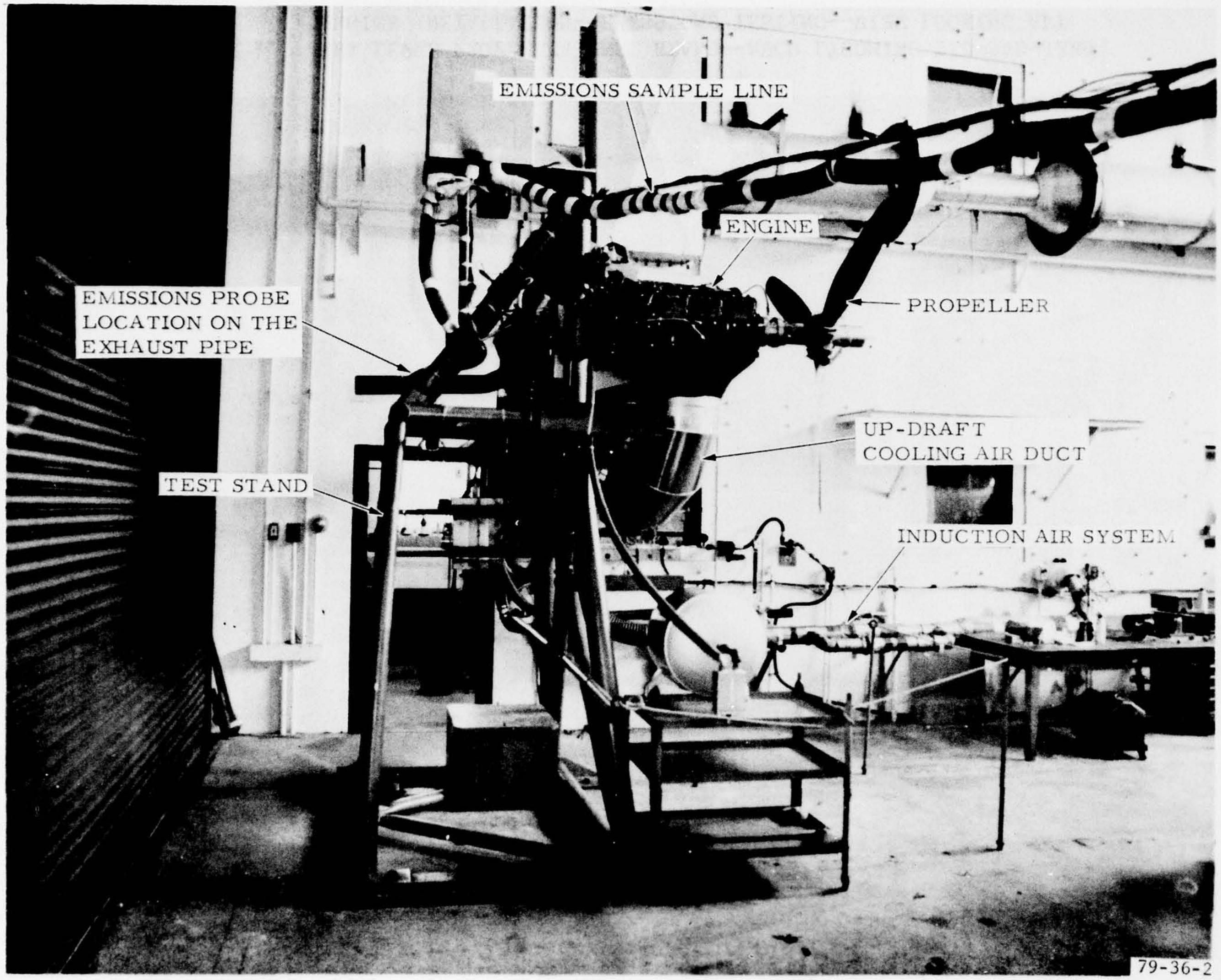


FIGURE 2. SEA LEVEL PROPELLER TEST STAND--AVCO LYCOMING TIO-540-J2BD ENGINE INSTALLATION--EMISSION TESTING--SIDE VIEW

(1) One basic air source--ambient air (heated and unheated)
(2) Ambient temperatures (20 to 140 degrees Fahrenheit (°F))
(3) Nominal sea level pressures (28.50 to 31.50 inches of mercury absolute (inHgA)
(4) Humidity (specific humidity--0 to 0.020 lb of water (H_2O) vapor/lb dry air)
(5) Fuel (100/130 octane aviation gasoline--a dedicated 5,000-gallon tank)

DESCRIPTION OF AIR INDUCTION SYSTEM AND AIRFLOW COMPUTATIONS.

The airflow system (induction system) utilized at NAFEC for testing light-aircraft piston engines is illustrated in figure 3. This system incorporated a redundant airflow measuring system for accuracy and reliability. In the high-flow measuring section NAFEC utilized a 4.0-inch orifice and an Autronics air meter (model 100-750S). The capability of this high-flow system ranged from 800 to 4,000 pounds per hour with an estimated tolerance in flow accuracy of +2 percent. The low-flow measuring section utilized a small 1.375-inch orifice and an Autronics air meter (model 100-100S). The capability of this system ranged from 80 to 800 pounds per hour with an estimated tolerance in flow accuracy of ±3 percent. The size of the basic air duct was 8.0 inches (inside diameter) for the high-flow system and 2.0 inches (inside diameter) for the low-flow system.

The total airflow was computed from the orifice differential pressure and induction air density using the following equation:

$$Wa\ (total) = (1891)\ (C_f)\ (d_o)^2 \left[(.03609)\ \Delta P_\rho\right]^{1/2} \qquad \text{(Reference 2)}$$

ΔP = inH_2O (differential air pressure)
ρ = lb/ft^3 (induction air density)
d_o = inches (orifice diameter)
C_f = flow coefficient for orifice (nondimensional)
1891 = conversion constant for airflow in pounds per hour (lb/h).

For the 4.0-inch orifice this equation simplifies to:

$$Wa = (19{,}061.3) \left[(.03609)\ \Delta P_\rho\right]^{1/2} = 3621.14\ (\Delta P_\rho)^{1/2}$$

For the 1.375-inch orifice this equation simplifies to:

$$Wa = (2{,}484.7) \left[(.03609)\ \Delta P_\rho\right]^{1/2} = 472.03\ (\Delta P_\rho)^{1/2}$$

DESCRIPTION OF FUEL-FLOW SYSTEM.

The fuel-flow system utilizied during the NAFEC light-aircraft piston engine emission tests incorporated rotameters and turboflow meters. The high-flow section incorporated a rotameter in series with a high-flow turbometer, while the low-flow section incorporated a low-flow turbometer in series with a low-flow rotometer. The high-flow system was capable of measureing fuel flows from 50 lb/h up to 500 lb/h with an estimated tolerance of ±1.0 percent. The low-flow system was capable of flow measurements ranging from 0-50 lb/h with an estimated tolerance of ±2.0 percent. Figure 4 illustrates the NAFEC fuel-flow system in schematic form.

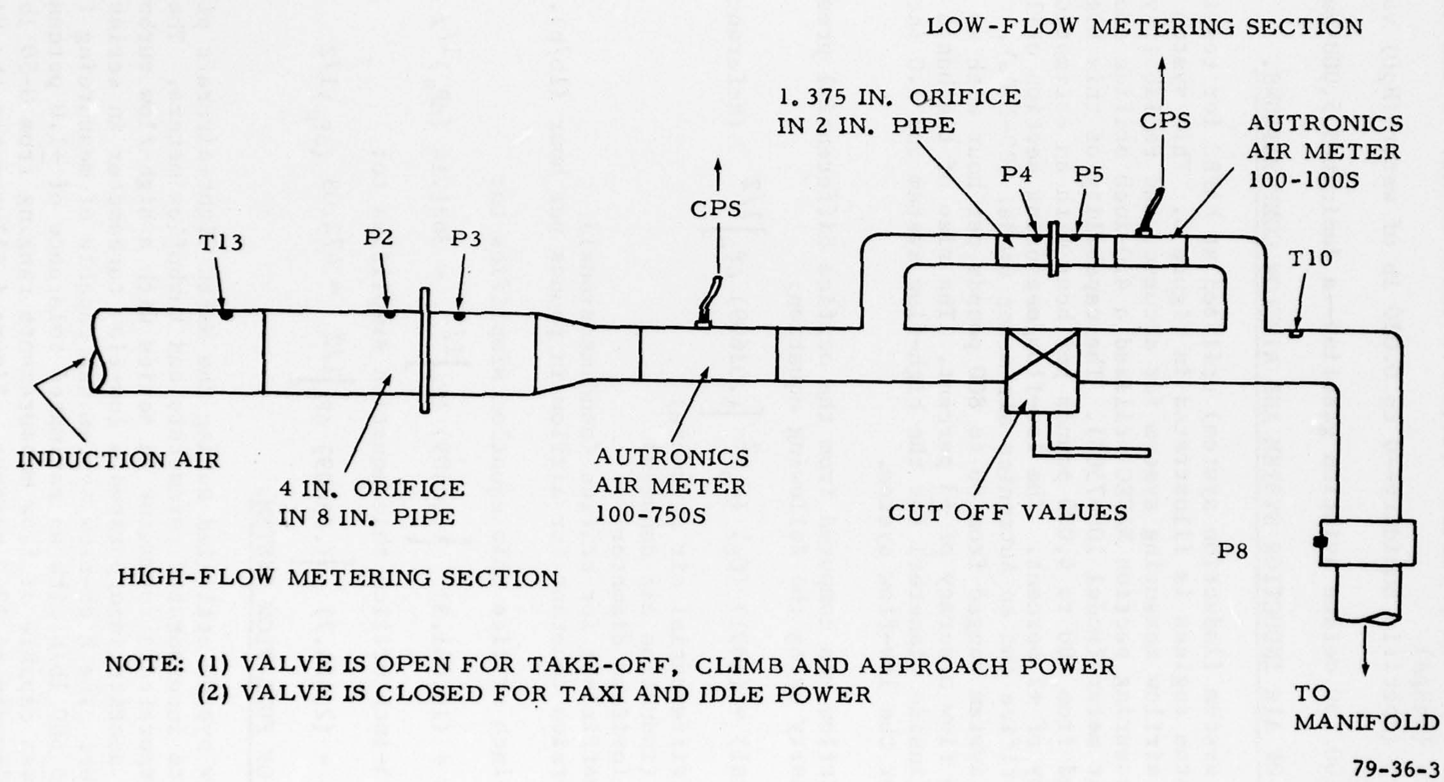


FIGURE 3. NAFEC AIR INDUCTION (AIRFLOW MEASUREMENT) SYSTEM FOR LIGHT-AIRCRAFT PISTON ENGINE EMISSION TESTS

DESCRIPTION OF COOLING AIR SYSTEM.

The NAFEC piston engine test facility also incorporated a system which provided cooling air (see figure 1) to the engine cylinders. The engine mounted in the test stand was enclosed in a simulated nacelle, and cooling air was provided to this enclosure from an external source. The cooling air temperature was maintained within $\pm 10°$ F of the induction air supply temperature for any specified set of test conditions. This not only minimized variations in temperature but also minimized variations in the specific weight of air for all test conditions. All of the basic cooling air tests conducted with the TIO-540-J2BD engine were conducted with differential cooling air pressures of 6.0 inH_2O. During taxi mode tests, the cooling air differential pressure was approximately equal to 0 inH_2O.

DESCRIPTION OF TEST PROCEDURES AND EPA STANDARDS.

The data presented in this report were measured while conducting tests in accordance with specific landing and takeoff cycles (LTO) and by modal lean-out tests. The basic EPA LTO cycle is defined in table 2.

The FAA/NAFEC contract and in-house test programs utilized an LTO cycle which was a modification of the table 2 test cycle. Table 3 defines this modified LTO cycle which was used to evaluate the total full-rich emission characteristics of light-aircraft piston engines.

TABLE 2. EPA FIVE-MODE LTO CYCLE

Mode No.	Mode Name	Time-In-Mode (Min.)	Power (%)	Engine Speed (%)
1	Taxi/idle (out)	12.0	*	*
2	Takeoff	0.3	100	100
3	Climb	5.0	75-100	*
4	Approach	6.0	40	*
5	Taxi/idle (in)	4.0	*	*

*Manufacturer's Recommended

TABLE 3. FAA/NAFEC SEVEN-MODE LTO CYCLE

Mode No.	Mode Name	Time-In-Mode (Min.)	Power (%)	Engine Speed (%)
1	Idle (out)	1.0	*	*
2	Taxi (out)	11.0	*	*
3	Takeoff	0.3	100	100
4	Climb	5.0	80	*
5	Approach	6.0	40	*
6	Taxi (in)	3.0	*	*
7	Idle (in)	1.0	*	*

*Manufacturer's Recommended

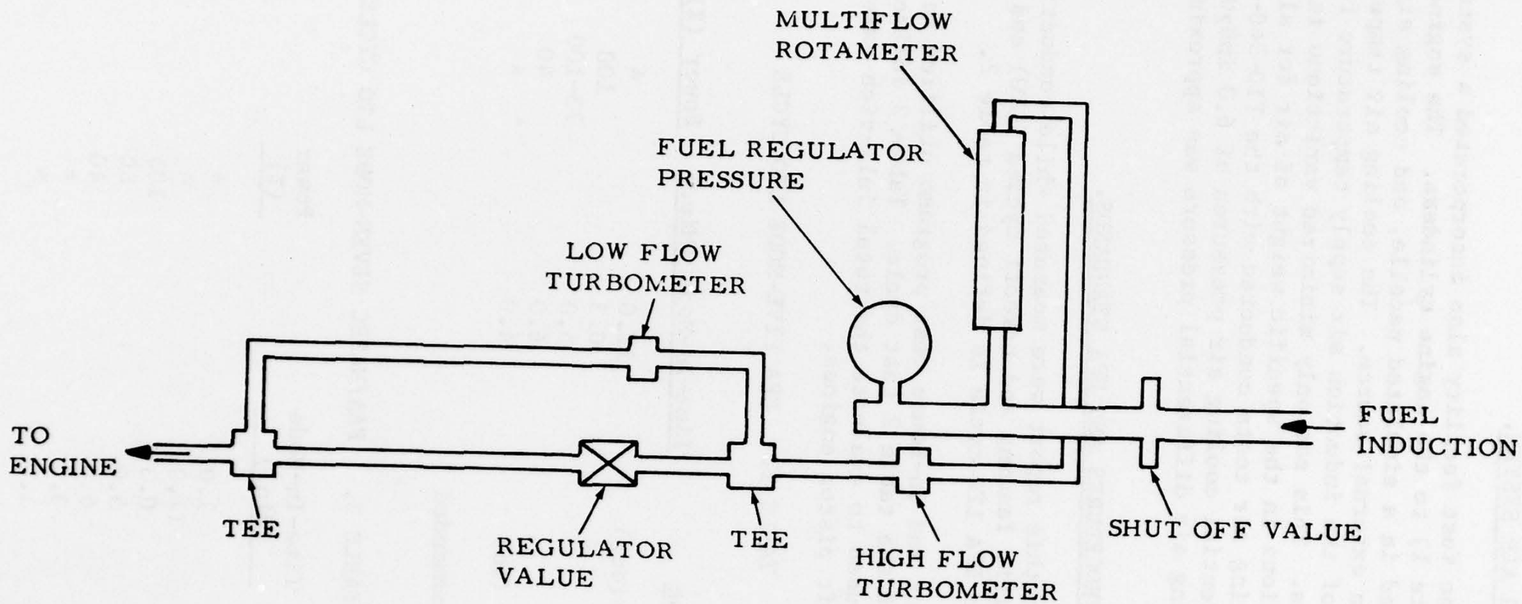


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FIGURE 4. NAFEC FUEL FLOW SYSTEM FOR LIGHT-AIRCRAFT PISTON ENGINE EMISSION TESTS

An additional assessment of the test data clearly indicates that further evaluations of the general aviation piston exhaust emission must be analyzed with the climb mode emissions at 100-percent and 75-percent power setting (tables 4 and 5). This would then provide the basis for a complete evaluation of test data and permit a total assessment of the proposed EPA standard based on LTO cyclic tolerances.

TABLE 4. MAXIMUM FIVE-MODE LTO CYCLE

Mode No.	Mode Name	Time-In-Mode (Min.)	Power (%)	Engine Speed (%)
1	Taxi (out)	12.0	*	*
2	Takeoff	0.3	100	100
3	Climb	5.0	100	100
4	Approach	6.0	40	*
5	Taxi (in)	4.0	*	*

*Manufacturer's Recommended

TABLE 5. MINIMUM FIVE-MODE LTO CYCLE

Mode No.	Mode Name	Time-In-Mode (Min)	Power (%)	Engine Speed (%)
1	Taxi (out)	12.0	*	*
2	Takeoff	0.3	100	100
3	Climb	5.0	75	*
4	Approach	6.0	40	*
5	Taxi (in)	4.0	*	*

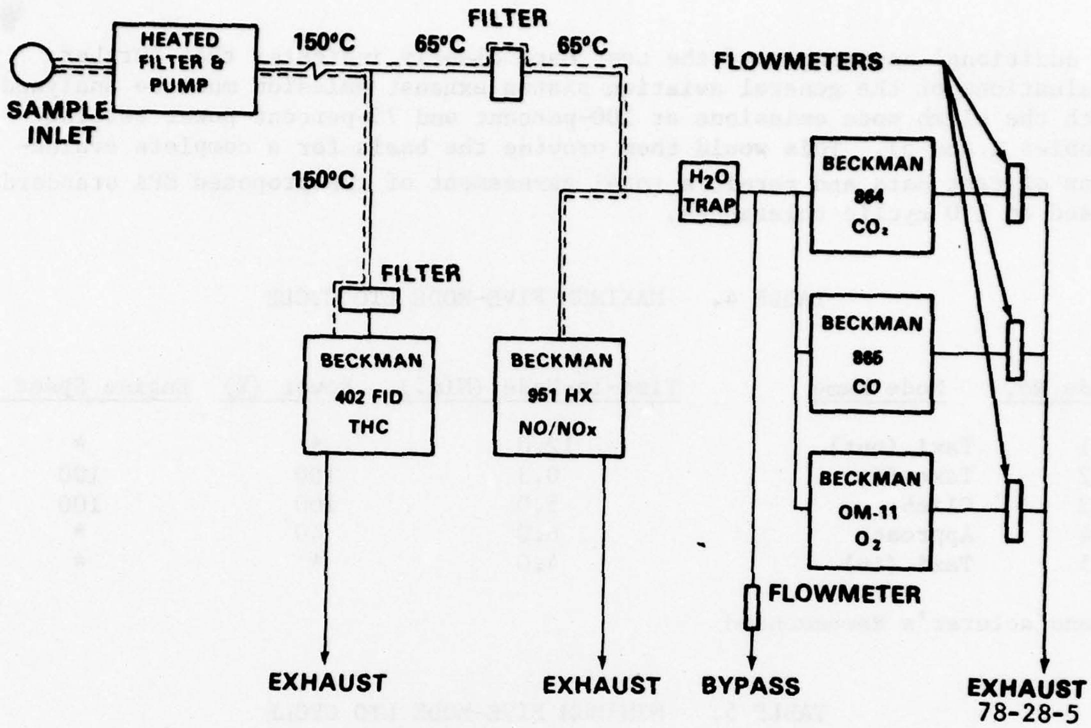
*Manufacturer's Recommended

The EPA Standards (reference 1) that were evaluated during this program were:

Carbon Monixide (CO)--0.042 lb/cycle/rated BHP
Unburned Hydrocarbon (HC)--0.0019 lb/cycle/rated BHP
Oxides of Nitrogen (NO_x)--0.0015 lb/cycle/rated BHP

DESCRIPTION OF EMISSIONS MEASUREMENT SYSTEM (Reference 3).

EMISSION ANALYZERS. The instrumentation used to monitor the exhaust emissions from general aviation piston engines was basically the same as that recommended by EPA, but with a number of modifications and additions to enhance the reliability and accuracy of the system. A schematic of the emissions measurement system is shown in figure 5.



- **CARBON DIOXIDE – CO_2**
  - NONDISPERSIVE INFRARED (NDIR)
  - RANGE 0-20%
  - REPEATABILITY ± 0.2% CO_2
- **CARBON MONOXIDE – CO**
  - NDIR
  - RANGE 0-20%
  - REPEATABILITY ± 0.2% CO
- **TOTAL HYDROCARBONS – THC**
  - FLAME IONIZATION DETECTOR (FID)
  - RANGE 0-150,000 ppm_C
  - MINIMUM SENSITIVITY 1.5 ppm_C
  - LINEAR TO 150,000 ppm_C
- **OXIDES OF NITROGEN – NO_X**
  - CHEMILUMINESCENT (CL)
  - RANGE 0-10,000 ppm
  - MINIMUM SENSITIVITY 0.1 ppm
- **OXYGEN – O_2**
  - POLARAGRAPHIC
  - RANGE 0-100%
  - REPEATABILITY 0.1% O_2
  - RESPONSE 200 ms

78-28-6

FIGURE 5. SCHEMATIC OF EMISSIONS MEASUREMENT SYSTEM AND ITS MEASUREMENT CHARACTERISTICS

EMISSION INSTRUMENTATION ACCURACY/MODIFICATION. The basic analysis instrumentation utilized for this system is explained in the following paragraphs.

Carbon Dioxide. The carbon dioxide (CO_2) subsystem is constructed around a Beckman model 864-23-2-4 nondispersive infrared analyzer (NDIR). This analyzer has a specified repeatability of ±1 percent of full scale for each operating range. The calibration ranges on this particular unit are: Range 1, 0 to 20 percent; Range 3, 0 to 5 percent. Stated accuracy for each range is, therefore, ±0.2 and ±0.05 percent, respectively.

Carbon Monoxide. The subsystem used to measure carbon monoxide (CO) is constructed around a Beckman model 865-X-4-4-4 NDIR. This analyzer has a specified repeatability of ±1 percent of full scale for ranges 1 and 2 and ±2 percent of full scale for range 3.

Range 1 has been calibrated for 0 to 20 percent by volume, range 2 for 0 to 1,000 parts per million (ppm) and range 3 for 0 to 100 ppm. The wide-range capability of this analyzer is made possible by using stacked sample cells which in effect give this analyzer six usable ranges when completely calibrated.

Effects of interfering gases, such as CO_2 and water vapor, were determined and reported by the factory. Interferences from 10 percent CO_2 were determined to be 12 ppm equivalent CO, and interferences from 4 percent water vapor were determined to be 6 ppm CO equivalent. Even though the interference from water vapor is negligible, a condenser is used in the CO/CO_2 subsystem to eliminate condensed water in the lines, analyzers, and flowmeters. This condensation would have decreased analyzer sensitivity and necessitated more frequent maintenance if it had been eliminated.

Total Hydrocarbons. The system that is used to measure total hydrocarbons is a modified Beckman model 402 heated flame ionization detector. This analyzer has a full-scale sensitivity that is adjustable to 150,000 ppm carbon with intermediate range multipliers 0.5, 0.1, 0.05, 0.01, 0.005, and 0.001 times full scale.

Repeatability for this analyzer is specified to be ±1 percent of full scale for each range. In addition, this modified analyzer is linear to the full-scale limit of 150,000 ppm carbon when properly adjusted. The two major modifications which were made to this analyzer were the installation of a very fine metering value in the sample capillary tube, and the installation of an accurate pressure transducer and digital readout to monitor sample pressure. Both of these modifications were necessary because of the extreme pressure sensitivity of the analyzer (figures 6 through 8). Correct instrument response depends on the amount of sample passing through a capillary tube; as a result, if there is too high a sample flow, the analyzer response becomes nonlinear when a high concentration gas is encountered. Sample flow may be controlled by varying the pressure on this capillary or increasing the length of the capillary. On this analyzer, linearity to 50,000-ppm carbon was obtained by reducing the sample pressure to 1.5 pounds per square inch gauge (psig). However, the need

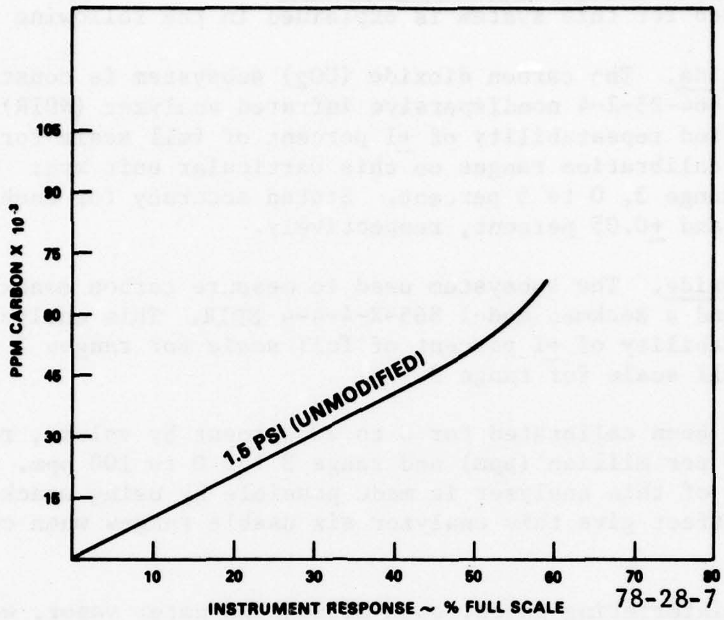


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Figure 3-7

FIGURE 6. BECKMAN MODEL 402 THC ANALYZER (1.5 PSI UNMODIFIED)

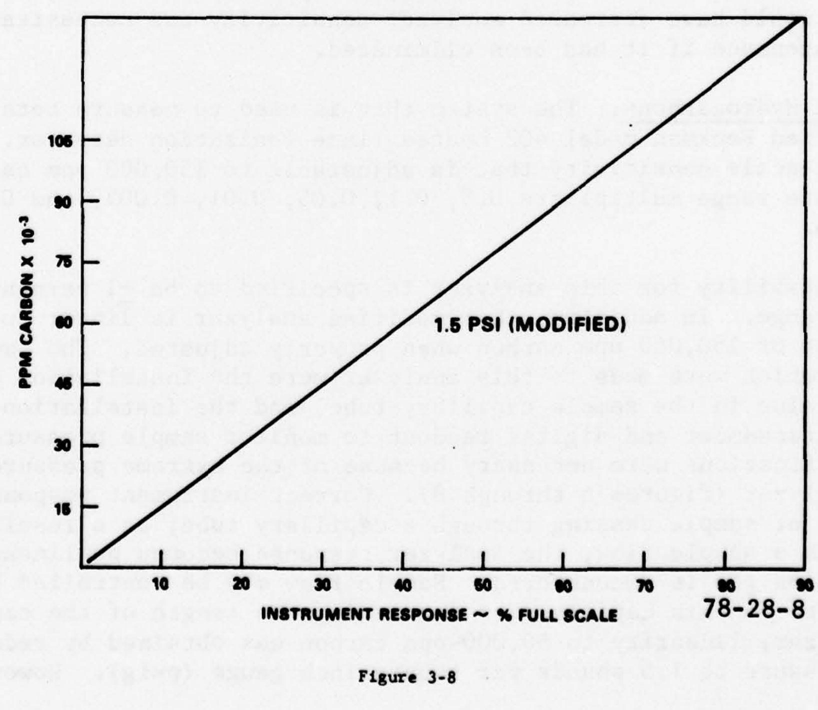

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Figure 3-8

FIGURE 7. BECKMAN MODEL 402 THC ANALYZER (1.5 PSI MODIFIED)

for linearity to 120,000-ppm carbon was anticipated. Further reduction of the sample pressure increased the noise level of the analyzer to an unacceptable level. In order to reduce the flow through the capillary without using a lower pressure, either the length or the resistance of the capillary had to be increased. The standard modification for this analyzer in order to limit flow is the installation of an additional length of capillary tubing. This procedure requires trial and error determination of proper capillary length and is a permanent modification that limits sensitivity at low hydrocarbon levels. By installing a metering valve in the capillary, flow could be selectively set at either low flow for linearity at high concentrations or high flow for greater sensitivity at low concentrations. Installation time was reduced by eliminating the cut-and-try procedure for determining capillary length.

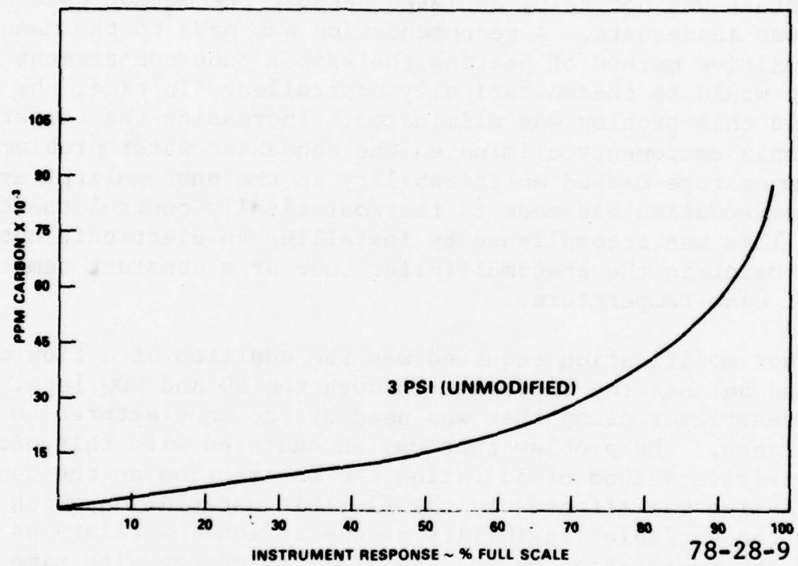


Figure 3-9

FIGURE 8. BECKMAN MODEL 402 THC ANALYZER (3 PSI UNMODIFIED)

The addition of a sensitive pressure transducer and digital readout to monitor sample pressure was needed since the pressure regulator and gauge supplied with the analyzer would not maintain the pressure setting accurately at low pressures. Using the digital pressure readout, the sample pressure could be monitored and easily maintained to within 0.05 inH_2O.

Oxides of Nitrogen. Oxides of nitrogen (NO_x) are measured by a modified Beckman model 951H atmospheric pressure, heated, chemiluminescent analyzer (CL). This analyzer has a full-scale range of 10,000 ppm with six intermediate ranges. Nominal minimum sensitivity is 0.1 ppm on the 10 ppm full-scale range.

The atmospheric pressure analyzer was chosen because of its simplicity, ease of maintenance, and compactness. Anticipated water vapor problems in the atmospheric pressure unit were to be handled by the heating of the internal sample train. Interference from CO_2 quenching, common in the atmospheric pressure type CL analyzer, was checked and found to be nonexistent.

A series of major modifications were performed by the manufacturer on this analyzer to insure compliance with specifications. One such modification was installed in order to maintain the temperature of the sample stream above the dew point of the sample gas. Originally this analyzer was specified to maintain a temperature of 140° F at all points in contact with the sample. After a survey of the 951H analyzers in use on FAA projects, it was determined that this temperature was not being achieved because the method used to heat the components was inadequate. A recommendation was made to the manufacturer to install a positive method of heating the sample tube compartment and reaction chamber that would be thermostatically controlled. In time, the modification was made, and this problem was eliminated. Increasing the temperature of the internal sample components eliminated the condensed water problem; however, the elevated temperature caused an instability in the photomulitplier tube output. Another recommendation was made to thermostatically control the temperature of this tube. This was accomplished by installing an electronic cooling jacket designed to maintain the photomultiplier tube at a constant temperature below the internal case temperature.

A further modification required was the addition of a flow control valve to adjust and balance the flow rate through the NO and NO_x legs. This valve replaced a restrictor clamp that was used by the manufacturer to set the NO to NO_x flow balance. The problem that was encountered with this clamp was that it was not a positive method of adjusting the restriction on the capillary. The clamp compression was affected by the flexible material on which the clamp was mounted and the variable flexibility of the teflon® capillary as it was heated. This caused the restriction on the capillary to change with time and caused permanent deformation of the capillary allowing only an adjustment that would increase the restriction.

Oxygen Measurement. Oxygen (O_2) was measured by a Beckman model OM-11 oxygen analyzer. This analyzer uses a polagraphic type sensor unit to measure oxygen concentration. An advanced sensor and amplification system combine to give an extremely fast response and high accuracy. Specified response for 90 percent of final reading is less than 200 milliseconds (ms) with an accuracy of less than ± 0.1-percent O_2. The range of this unit is a fixed 0 to 100 percent O_2 concentration.

EMISSIONS INSTRUMENTATION MODIFICATION STATUS DURING THE TESTING OF THE TIO-540-J2BD ENGINE. The tests conducted with the Avco Lycoming TIO-540-J2BD engine utilized the Beckman model OM-11 oxygen (O_2) analyzer and a prototype Beckman model 951H oxides of nitrogrn (NO_x) analyzer. All of the emissions and exhaust constituent-measuring instruments/analyzers incorporated the latest specified modifications described in this report.

DESCRIPTION OF SAMPLE HANDLING SYSTEM.

Exhaust samples are transported to the analysis instrumentation under pressure through a 35-foot-long, 3/8-inch O.D., heated, stainless steel sample line. The gas is first filtered and then pumped through this line by a heated Metal Bellows model MB-158 high temperature stainless steel sample pump. The pump, filter, and line are maintained at a temperature of 300° ±4° F to prevent condensation of water vapor and hydrocarbons. At the instrument console, the sample is split to feed the hydrocarbon, oxides of nitrogen, and $CO/CO_2/O_2$ subsystems which require different temperature conditioning. The sample gas to the total hydrocarbon subsystem is maintained at 300° F while the temperature of remaining sample gas to the NO_x and $CO/CO_2/O_2$ system is allowed to drop to 150° F. Gas routed to the oxides of nitrogen subsystem is then maintained at 150° F, while the gas to the $CO/CO_2/O_2$ subsystem is passed through a 32° F condenser to remove any water vapor present in the sample. Flow rates to each analyzer are controlled by a fine-metering valve and are maintained at predetermined values to minimize sample transport and system response time. Flow is monitored at the exhaust of each analyzer by three 15-centimeter (cm) rotameters. Two bypasses are incorporated into the system to keep sample transport time through the lines and condenser to a minimum without causing adverse pressure effects in the analyzers.

DESCRIPTION OF FILTRATION SYSTEM.

Particulates are removed from the sample at three locations in the system, thereby minimizing downtime due to contaminated sample lines and analyzers (figure 5). Upstream of the main sample pump is a heated clamshell-type stainless steel filter body fitted with a Whatman GF/C glass fiber paper filter element capable of retaining particles in the 0.1 micron range. A similar filter is located in the total hydrocarbon analyzer upstream of the sample capillary. A Mine Safety Appliances (MSA) type H ultra filter capable of retaining 0.3 micron particles is located at the inlet to the oxides of nitrogen and $CO/CO_2/O_2$ subsystems.

COMPUTATION PROCEDURES.

The calculations required to convert exhaust emission measurements into mass emissions are the subject of this section.

Exhaust emission tests were designed to measure CO_2, CO, unburned hydrocarbons (HC), NO_x, and exhaust excess O_2 concentrations in percent or ppm by volume. Mass emissions were determined through calculations utilizing the data obtained during the simulation of the aircraft LTO cycle and from modal lean-out data.

COMBUSTION EQUATION. The basic combustion equation can be expressed very simply:

Fuel + Air = Exhaust Constituents

An initial examination of the problem requires the following simplifying assumptions:

1. The fuel consists solely of compounds of carbon and hydrogen.

2. The air is a mixture of oxygen and inert nitrogen in the volumetric ratio of 3.764 parts apparent nitrogen to 1.0 part oxygen (see appendix B for additional details).

3. If a stoichiometric combustion process exists, the fuel and air are supplied in chemically correct proportions.

4. The fuel (which consists usually of a complex mixture of hydrocarbons) can be represented by a single hydrocarbon having the same carbon-hydrogen ratio and molecular weight as the fuel; usually C_8H_{17} as an average fuel.

Applying the above assumptions for stoichiometric conditions, a useful general reaction equation for hydrocarbon fuel is:

$$M_fC_8H_{17} + M_a\left(O_2 + 3.764N_2 + M_wH_2O\right) \rightarrow M_1CO_2 + M_3H_2O + M_5N_2 \quad (1)$$

(References 4 and 5)

Where
M_f = Moles of Fuel
M_a = Moles of Air or Oxygen
M_1 = Moles of Carbon Dioxide (CO_2)
M_3 = Moles of Condensed Water (H_2O)
M_5 = Moles of Nitrogen (N_2) - Exhaust
$3.764M_a$ = Moles of Nitrogen (N_2) - In Air
M_aM_w = Moles of Humidity (H_2O) - In Air

The above equation is applicable to dry air when M_w is equal to zero.

From equation (1), and assuming dry air with one mole of fuel (M_f=1.0), the stoichiometric fuel-air ratio may be expressed as:

$$(F/A)_s = \frac{\text{Wt. Fuel}}{\text{Wt. Air Required}} = \frac{12.011\ (8) + 1.008\ (17)}{12.25\ [32.000 + 3.764(28.161)]} \quad (2)$$

$$(F/A)_s = \frac{113.224}{12.25(137.998)} = 0.067$$

The mass carbon-hydrogen ratio of the fuel may be expressed as follows:

$$C/H = \frac{12.001(8)}{1.008(17)} = \frac{96.088}{17.136} = 5.607 \quad (3)$$

The atomic hydrogen-carbon ratio is:

$$17/8 = 2.125 \quad (4)$$

The stoichiometric fuel-air ratio may be expressed as a function of the mass carbon-hydrogen ratio of the fuel. The derivation of this equation is presented in reference 4.

$$(F/A)_s = \frac{C/H + 1}{11.5(C/H+3)} \quad (5)$$

$(F/A)_s$ = 0.067 for a mass carbon-hydrogen ratio of 5.607

With rich (excess fuel) mixtures, which are typical for general aviation piston engines, some of the chemical energy will not be liberated because there is not enough air to permit complete oxidation of the fuel. Combustion under such conditions is an involved process. By making certain simplifying assumptions based on test results, the effect of rich mixtures may be calculated with reasonable accuracy.

For rich (excess fuel) mixtures, equation (1) will now be rewritten to express the effects of incomplete combustion:

$$M_f C_8H_{17} + M_a(O_2 + 3.764N_2 + M_w H_2O) \rightarrow M_1 CO_2 + M_2 CO + M_3 H_2O + M_4 H_2 +$$
$$M_5 N_2 + M_6 NO + M_7 CH_4 + M_8 O_2 + M_9 C \quad (6)$$

Since only a limited number of the exhaust constituents were measured during the testing of general aviation piston engines, the above equation can only be solved by applying certain expeditious assumptions and emperical data.

An important requirement was the accurate measurement of air and fuel flows. These parameters provide the data for determining engine mass flow (W_m), and with the aid of figure 9 (developed from reference 6), it is a simple computation to calculate the total moles (M_{tp}) of exhaust products being expelled by general aviation piston engines.

$$(M_{tp}) = W_m \text{ (engine mass flow)} \div \text{(exh. mol. wt)} \quad (7)$$

Since the unburned hydrocarbons (HC) and oxides of nitrogen (NO_x) are measured wet, it becomes a very simple matter to compute the moles of HC and NO_x that are produced by light-aircraft piston engines.

$$M_7 \text{ (Moles of HC)} = (\text{ppm} \div 10^6) \times M_{tp} \quad (8)$$

$$M_6 \text{ (Moles of } NO_x) = (\text{ppm} \div 10^6) \times M_{tp} \quad (9)$$

If the dry products (M_{dp}) of combustion are separated from the total exhaust products (M_{tp}), it is possible to develop a partial solution for five of the products specified in equation 6.

This can be accomplished as follows:

The summation of the mole fractions $(MF)_d$ for dry products is

$$m_1 + m_2 + m_4 + m_5 + m_8 = 1.0000 \quad (10)$$

$m_1 = MF(CO_2) = \%CO_2$ (measured dry), expressed as a fraction

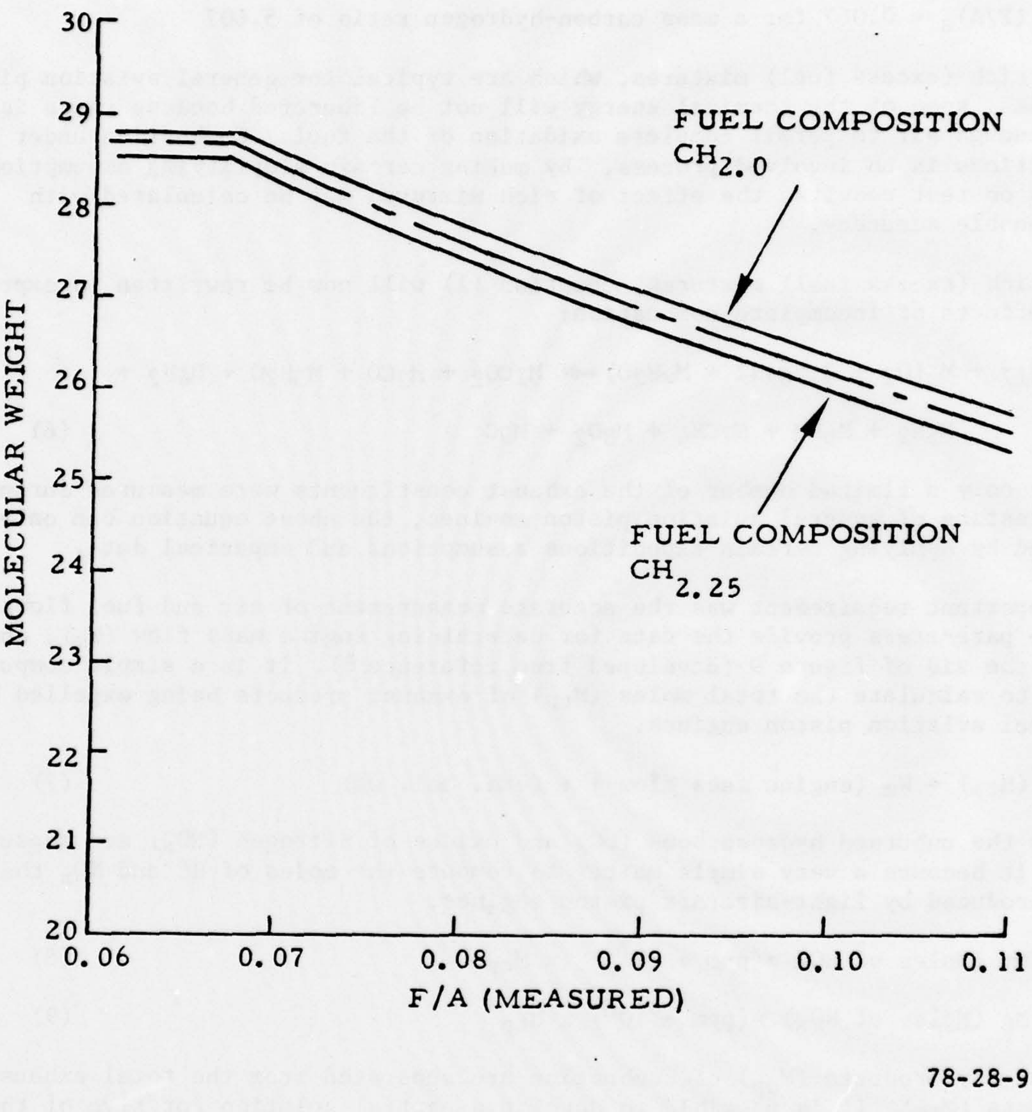


FIGURE 9. EXHAUST GAS MOLECULAR WEIGHTS

$m_2 = MF(CO) = \%CO$ (measured dry), expressed as a fraction

$m_4 = MF(H_2) = K_4\ (\%CO)$ (see figure 10, also references 5, 6, and 7), expressed as a fraction

$m_8 = MF(O_2) = \%O_2$ (measured dry), expressed as a fraction

$$m_5 = 1.0000 - (m_1 + m_2 + m_4 + m_8) = \%N_2 \text{ (dry), expressed as a fraction} \quad (11)$$

Utilizing the nitrogen balance equation, it is now possible to determine the moles of nitrogen that are being exhausted from the engine.

$$M_5 = 3.764 M_a - (M_6 \div 2);\ M_6 = \text{moles (NO)} \quad (12)$$

The moles of exhaust dry products (M_{dp}) may now be determined by dividing equation 12 by equation 11.

$$M_{dp} = M_5 \div M5 \quad (13)$$

Using all the information available from equations (7), (8), (9), (10), (11), (12), and (13), it is now possible to determine the molar quantities for seven exhaust products specified in equation 6.

$$\text{Moles } (CO_2) = M_1 = m_1 \times M_{dp} \quad (14)$$

$$\text{Moles } (CO) = M_2 = m_2 \times M_{dp} \quad (15)$$

$$\text{Moles } (H_2) = M_4 = m_4 \times M_{dp} \quad (16)$$

$$\text{Moles } (CO_2) = M_5 = m_5 \times M_{dp} \quad (17)$$

$$\text{Moles } (O_2) = M_8 = m_8 \times M_{dp} \quad (18)$$

$$\text{Moles } (CH_4) = M_7 = (ppm \div 10^6) \times M_{tp} \quad (19)$$

$$\text{Moles } (NO) = M_6 = (ppm \div 10^6) \times M_{tp} \quad (20)$$

To determine M_3 (moles of condensed H_2O), it is now appropriate to apply the oxygen balance equation.

$$M_3 = M_a\ (2 + M_w) - (2M_1 + M_2 + M_6 + 2M_8) = \text{Moles } (H_2O) \quad (21)$$

The remaining constituent specified in equation 6 may now be determined from the carbon balance equation 22.

$$M_9 = 8M_f - (M_1 + M_2 + M_7) \quad (22)$$

A check for the total number of exhaust moles (M_{tp}), calculated from equation 9, may now be determined from equation 23.

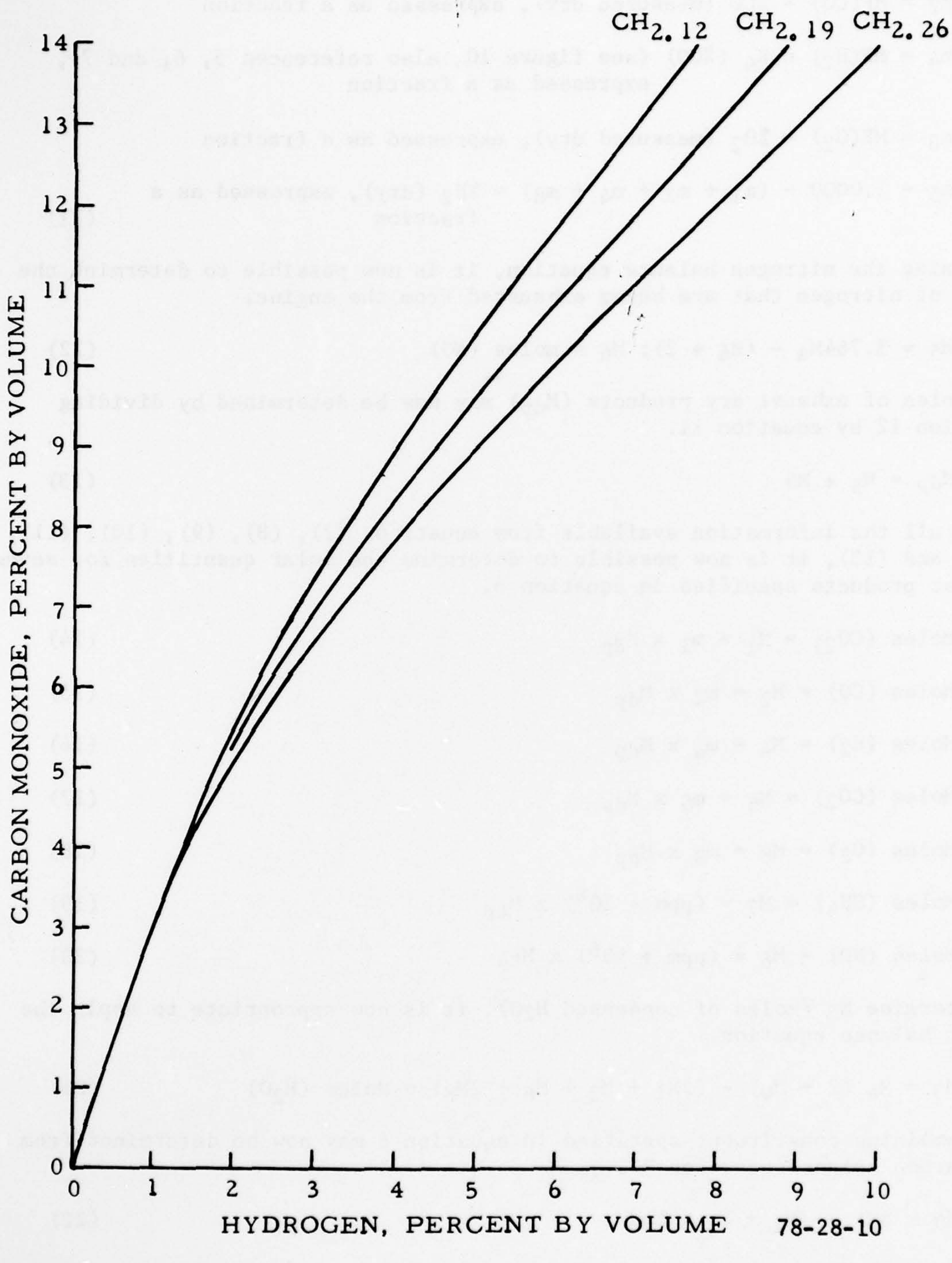


FIGURE 10. RELATION OF CARBON MONOXIDE AND HYDROGEN

$$M_{tp} = M_1 + M_2 + M_3 + M_4 + M_5 + M_6 + M_7 + M_8 + M_9 \quad (23)$$

$$\dot{m}_1 + \dot{m}_2 + \dot{m}_3 + \dot{m}_4 + \dot{m}_5 + \dot{m}_6 + \dot{m}_7 + \dot{m}_8 + \dot{m}_9 = 1.0000 \quad (24)$$

$$\dot{m}_1 = MF(CO_2) = M_1 \div M_{tp}$$

$$\dot{m}_2 = MF(CO) = M_2 \div M_{tp}$$

$$\dot{m}_3 = MF(H_2O) = M_3 \div M_{tp}$$

$$\dot{m}_4 = MH(H_2) = M_4 \div M_{tp}$$

$$\dot{m}_5 = MF(N_2) = M_5 \div M_{tp}$$

$$\dot{m}_6 = MH(NO) = M_6 \div M_{tp}$$

$$\dot{m}_7 = MF(CH_4) = M_7 \div M_{tp}$$

$$\dot{m}_8 = MF(O_2) = M_8 \div M_{tp}$$

$$\dot{m}_9 = MF(C) = M_9 \div M_{tp}.$$

The exhaust constituent mass flow rates may be computed in the following manner using each exhaust constituents molar constant with the appropriate molecular weight.

$$M_1 \times 44.011 = CO_2 \text{ in lb/h} \quad (25)$$

$$M_2 \times 28.011 = CO \text{ in lb/h} \quad (26)$$

$$M_3 \times 18.016 = H_2O \text{ in lb/h} \quad (27)$$

$$M_4 \times 2.016 = H_2 \text{ in lb/h} \quad (28)$$

$$M_5 \times 28.161 = N_2 \text{ in lb/h} \quad (29)$$

$$M_6 \times 30.008 = NO \text{ in lb/h} \quad (30)$$

$$M_7 \times 16.043 = CH_4 \text{ in lb/h} \quad (31)$$

$$M_8 \times 32.000 = O_2 \text{ in lb/h} \quad (32)$$

$$M_9 \times 12.011 = C \text{ in lb/h} \quad (33)$$

The exhaust fuel flow (W_{fe}), based on exhaust constituents, can now be calculated on a constituent-by-constituent basis as follows:

$$(M_1 + M_2 + M_9) \times 12.011 = \text{lb/h} \quad (34)$$

$$M_7 \times 16.043 = \text{lb/h} \quad (35)$$

$$(M_3 - M_a M_w) + M_4 \times 2.016 \tag{36}$$

$$W_{fe} = (34) + (35) + (36) = \text{lb/h} \tag{37}$$

In a similar manner the exhaust airflow (W_{ae}) can also be calculated on a constituent-by-constituent basis:

$$M_1 \times 32.000 = \text{lb/h} \tag{38}$$

$$M_2 \times 16.000 = \text{lb/h} \tag{39}$$

$$(M_3 \times 16.000) + (M_a M_w \times 18.016) = \text{lb/h} \tag{40}$$

$$M_5 \times 28.161 = \text{lb/h} \tag{41}$$

$$M_6 \times 30.008 = \text{lb/h} \tag{42}$$

$$M_8 \times 32.000 = \text{lb/h} \tag{43}$$

$$W_{ae} = \Sigma\ (38) \leftrightarrow (43) = \text{lb/h} \tag{44}$$

Using equations (37) and (44) it is now possible to determine a calculated fuel-air ratio on the basis of total exhaust constituents.

$$(F/A)_{\text{calculated}} = (37) \div (44) \tag{45}$$

RESULTS

GENERAL COMMENTS.

General aviation pistion engine emission tests were conducted to provide the following categories of data:

1. Full-rich (or production fuel schedule) baseline data for each power mode specified in the LTO test cycle.

2. Lean-out data for each power mode specified in the LTO test cycle.

3. Data for each power mode specified in the LTO test cycle utilized cooling air flow ΔP=6.0 inH_2O at takeoff, climb, and approach powers.

RESULTS OF BASELINE TESTS (LANDING-TAKEOFF CYCLE EFFECTS).

Based on an analysis of the factors affecting piston engine emissions (time in mode, F/A, ambient conditions, etc.), it can be shown that the mode conditions having the greatest influence on the gross pollutant levels produced by the combustion process are taxi, approach, and climb when using the LTO cycle defined in tables 3, 4, and 5. The five-mode LTO cycle shows that approximately 99 percent of the total cycle time (27.3-min) is attributed to these three modal conditions. Furthermore, the taxi modes (both out and in) account for

slightly less than 59 percent of the total cycle time. The remainder of the time is almost equally apportioned to the approach and climb modes (22 and 18 percent, respectively).

As a result of these time apportionments, it was decided that an investigation and evaluation of the data should be undertaken to determine which mode(s) has the greatest influence on improving general aviation piston engine emissions. The subsequent sections of this report will show the exhaust emissions characteristics for a Avco Lycoming TIO-540-J2BD engine (S/N 890-X) and what improvements are technically feasible within the limits of safe aircraft/engine operational requirements based on sea level propeller test stand evaluations conducted at NAFEC.

The first set of data to be presented and evaluated are the five-mode baseline runs conducted to establish the current production full-rich exhaust emissions characteristics of the TIO-540-J2BD engine. These are summarized in tabular form in appendix C (see tables C-1 through C-21) and includes data that were obtained for a range of sea level ambient conditions, specified as follows:

Induction air temperature (T_i) = 50° F to 140° F
Cooling air temperature (T_c) = $T_i \pm 10°$ F
Induction air pressure (P_i) = 29.20 to 30.50 inHgA
Induction air density (ρ) = 0.0675 to 0.0795 lb/ft^3

Figures 11 through 16 present five-mode baseline data in bargraph form (for different sea level ambient conditions). It also compares the total emissions characteristics of the TIO-540-J2BD engine (current production configuration) with the proposed EPA standards as a function of percent of standard. The data that were utilized to develop figures 11 through 16 are tabulated in appendix C and plotted in various forms for analysis and evaluation in figures C-1 through C-25.

RESULTS OF LEAN-OUT TESTS.

In the subsequent sections of this report, it will be shown what improvements can be achieved as a result of making lean-out adjustments to the fuel metering device: (1) taxi mode only, (2) taxi and approach modes combined, and (3) leaning-out the climb mode to "best power" in combination with taxi and approach mode leaning.

EFFECTS OF LEANING-OUT ON CO EMISSIONS. The test data obtained as a result of NAFEC testing the Avco Lycoming TIO-540-J2BD have been evaluated on the basis of leaning-out the taxi, approach, and climb modes while continuing the operation of the test engine at the production rich and lean limits in the takeoff mode. The results of leaning-out under this procedure are shown in bargraph form in figures 12 and 13.

When the taxi modes (out and in) were leaned-out from the production rich or lean limits to a fuel-air ratio of 0.088 (see figure 12), CO emissions are reduced approximately 25 percent. However, adjustments to the taxi mode fuel schedule alone are not sufficient to bring the total five-mode LTO cycle CO

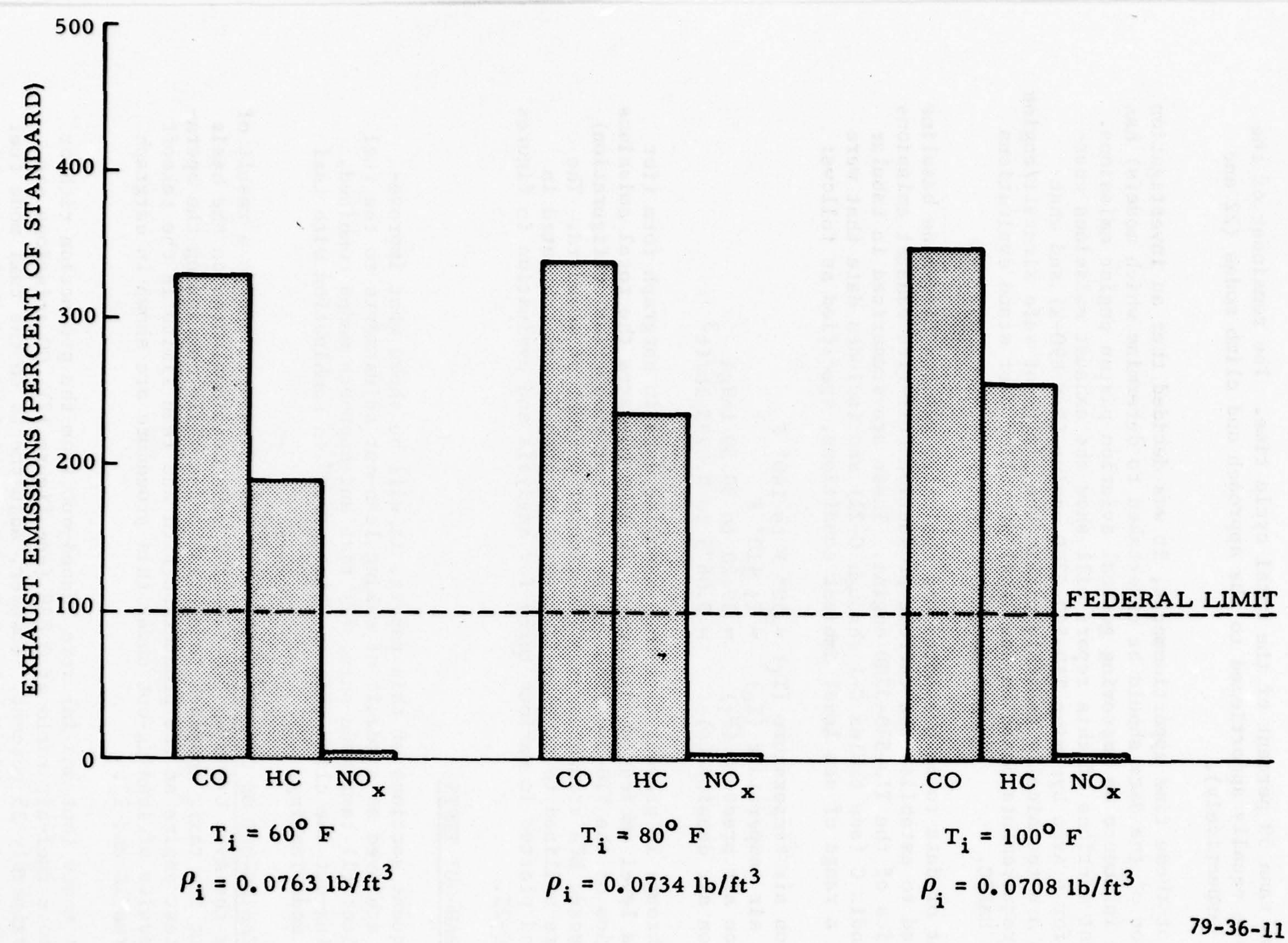


FIGURE 11. TOTAL EMISSIONS CHARACTERISTICS FOR AN AVCO LYCOMING TIO-540-J2BD ENGINE OPERATING UNDER VARYING SEA LEVEL INDUCTION AIR TEMPERATURES--TABLE 5 MINIMUM FIVE-MODE LTO CYCLE--FULL RICH

NOTE:

1. THIS FIGURE IS BASED ON THE TABLE 5 LTO CYCLE WITH THE CLIMB MODE AT APPROXIMATELY 75-80 PERCENT POWER.
2. THE MINIMUM F/A RATIO SETTING FOR THIS FIGURE IS 0.067 FOR THE APPROACH MODE; THE CLIMB MODE WAS SET FOR THE BEST POWER F/A = 0.0775; THE TAXI MODE WAS SET FOR THE MINIMUM FUEL FLOW (22 lb/h) THAT WOULD STILL PRODUCE ACCEPTABLE TRANSIENT CAPABILITIES (GOOD ACCELERATIONS FROM TAXI TO 7.0); THE T.O. MODE WAS MAINTAINED AT FULL RICH. THESE SETTINGS APPLY TO THE LOWEST SET OF BARGRAPHS SHOWN.

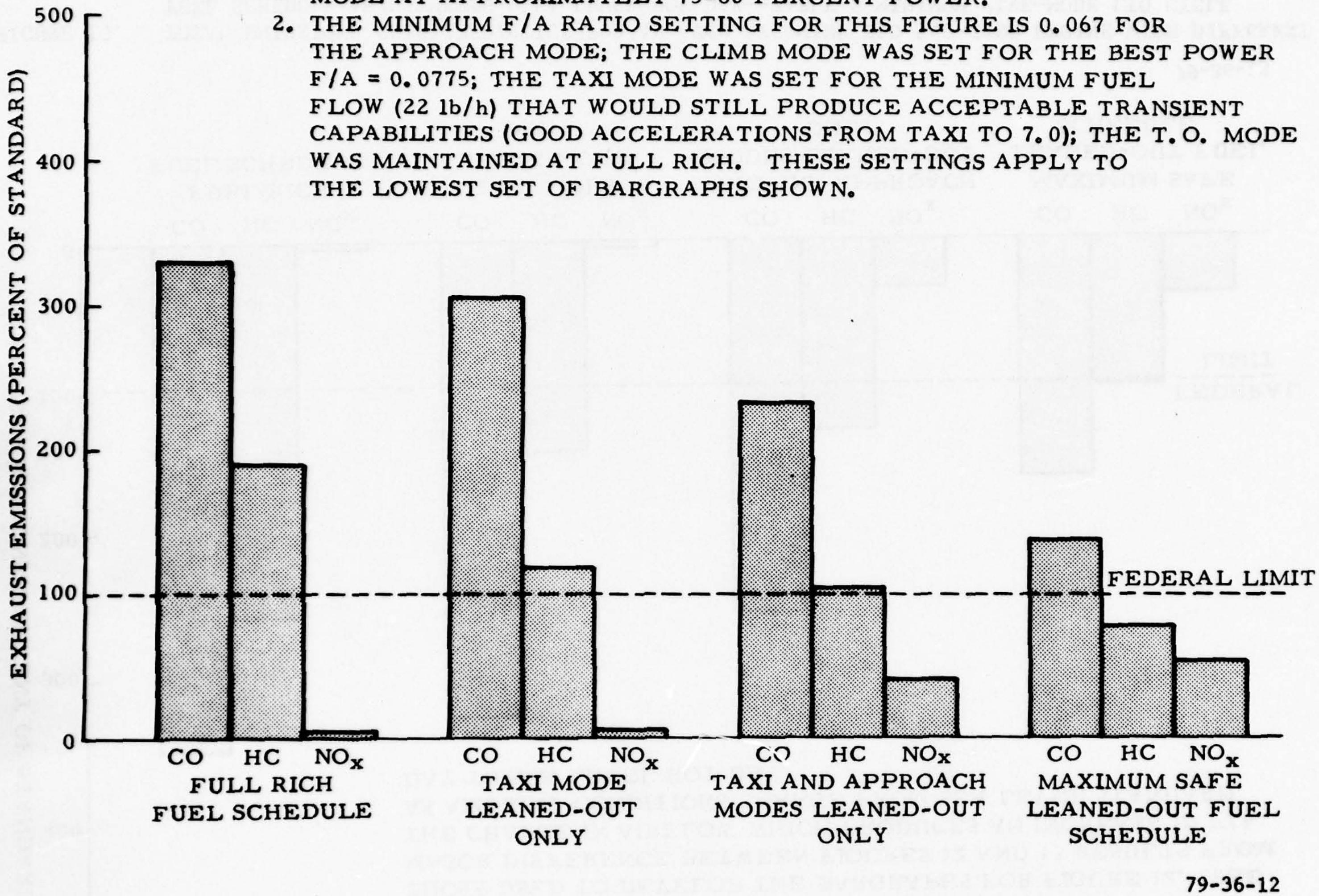


FIGURE 12. TOTAL EMISSIONS CHARACTERISTICS FOR AN AVCO LYCOMING TIO-540-J2BD ENGINE WITH DIFFERENT FUEL SCHEDULE ADJUSTMENTS--SEA LEVEL STANDARD DAY

NOTE:

1. THIS FIGURE IS BASED ON THE TABLE 5 LTO CYCLE WITH THE CLIMB MODE AT APPROXIMATELY 75-80 PERCENT POWER.
2. THE FUEL FLOW SETTINGS ARE APPROXIMATELY THE SAME AS THOSE USED TO DEVELOP THE BARGRAPHS FOR FIGURE 12. THE MAJOR DIFFERENCE BETWEEN FIGURES 12 AND 13 RESULTS FROM THE CHANGE IN AIRFLOW WHICH PRODUCES AN INCREASE IN F/A AS AMBIENT CONDITIONS CHANGE FROM SEA LEVEL STANDARD DAY TO SEA LEVEL HOT DAY.

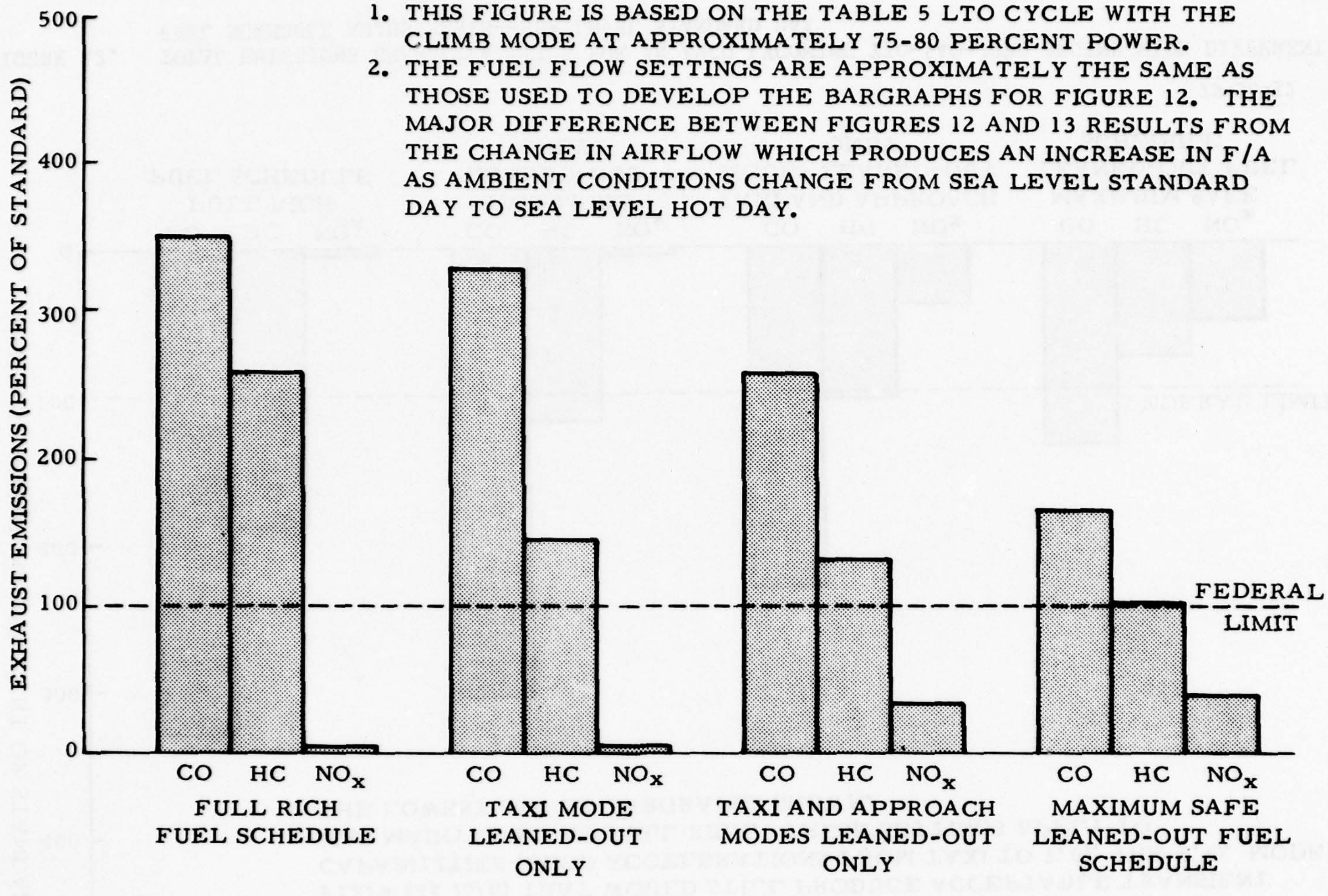


FIGURE 13. TOTAL EMISSIONS CHARACTERISTICS FOR AN AVCO LYCOMING TIO-540-J2BD ENGINE WITH DIFFERENT FUEL SCHEDULE ADJUSTMENTS--SEA LEVEL HOT DAY--TABLE 5 MINIMUM FIVE-MODE LTO CYCLE

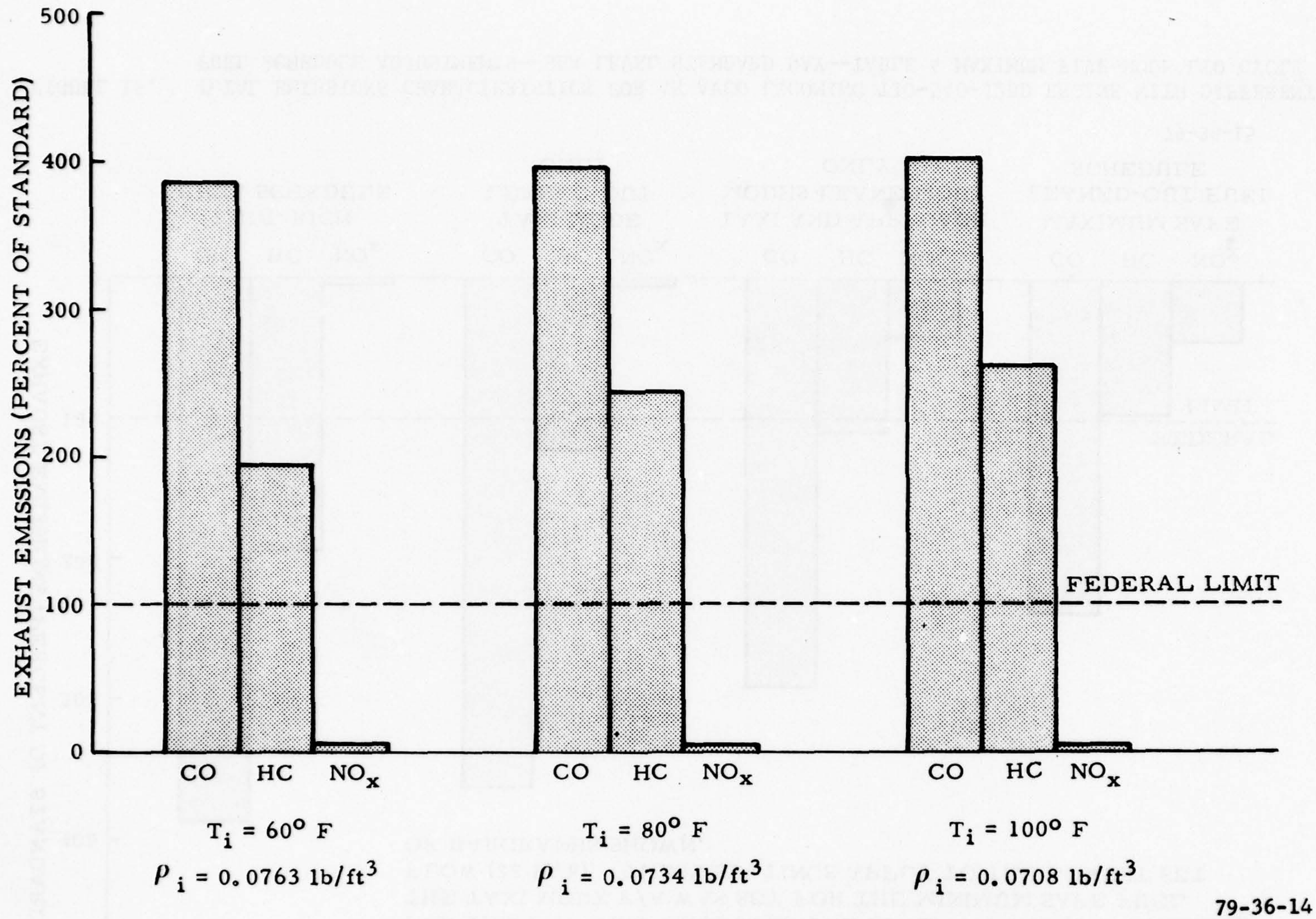


FIGURE 14. TOTAL EMISSIONS CHARACTERISTICS FOR AN AVCO LYCOMING TIO-540-J2BD ENGINE OPERATING UNDER VARYING SEA LEVEL INDUCTION AIR TEMPERATURES--TABLE 4 MAXIMUM FIVE-MODE LTO CYCLE--FULL RICH

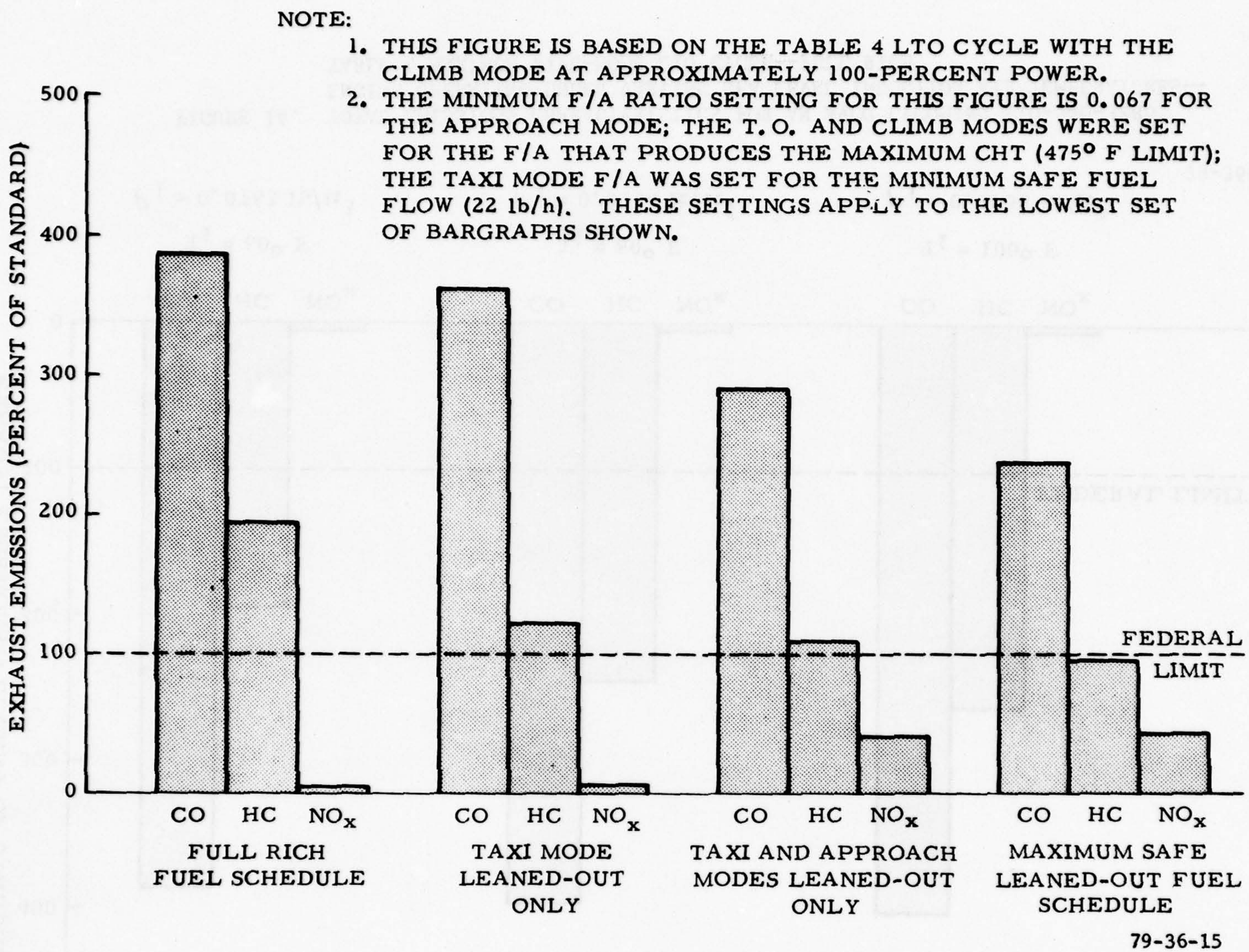


FIGURE 15. TOTAL EMISSIONS CHARACTERISTICS FOR AN AVCO LYCOMING TIO-540-J2BD ENGINE WITH DIFFERENT FUEL SCHEDULE ADJUSTMENTS--SEA LEVEL STANDARD DAY--TABLE 4 MAXIMUM FIVE-MODE LTO CYCLE

NOTE:

1. THIS FIGURE IS BASED ON THE TABLE 4 LTO CYCLE WITH THE CLIMB MODE AT APPROXIMATELY 100-PERCENT POWER.
2. THE FUEL FLOW SETTINGS ARE APPROXIMATELY THE SAME AS THOSE USED TO DEVELOP THE BARGRAPHS FOR FIGURE 15. THE MAJOR DIFFERENCE BETWEEN FIGURES 15 AND 16 RESULTS FROM THE CHANGE IN AIRFLOW WHICH PRODUCES AN INCREASE IN F/A AS THE AMBIENT CONDITIONS CHANGE FROM SEA LEVEL STANDARD DAY TO SEA LEVEL HOT DAY.

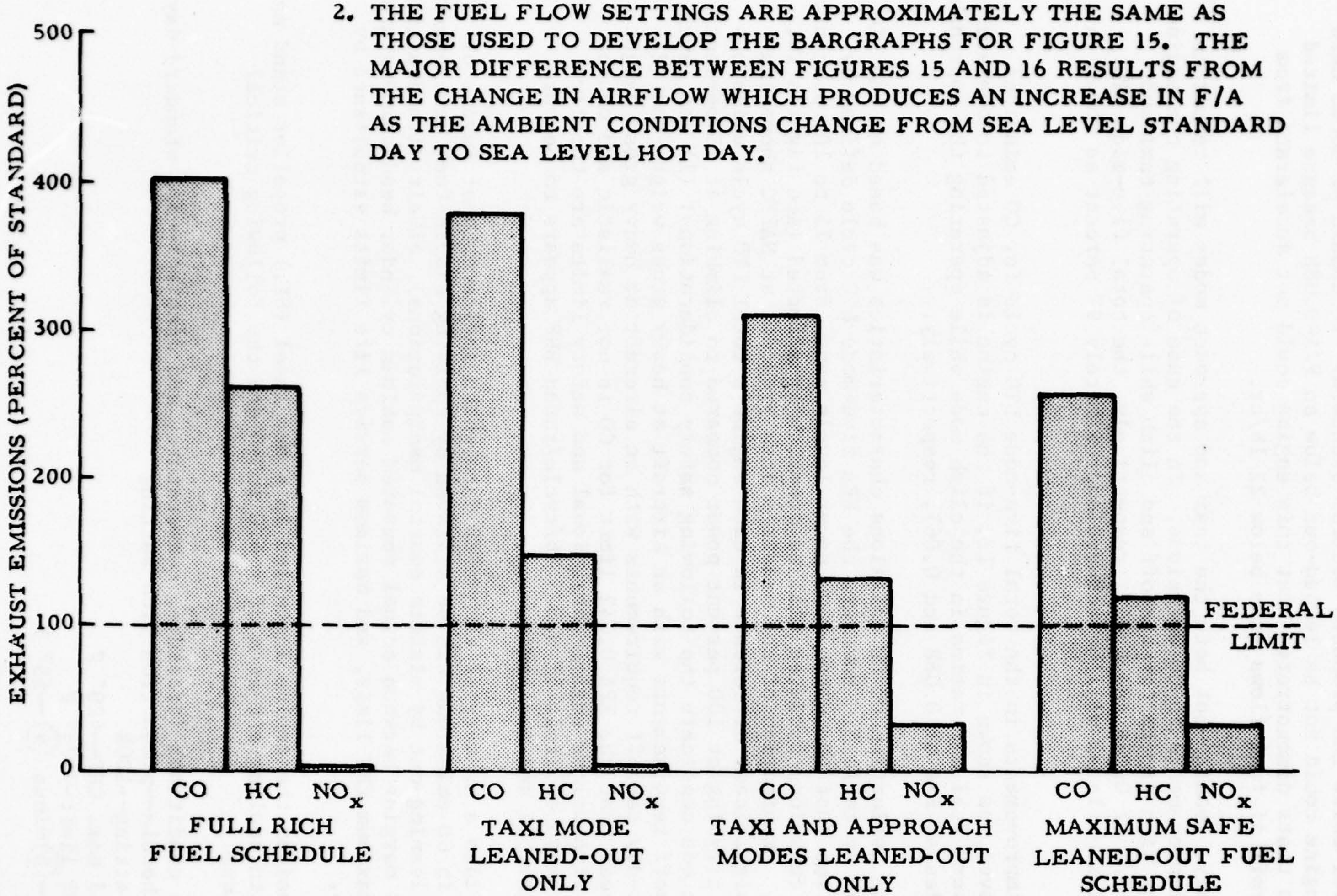


FIGURE 16. TOTAL EMISSIONS CHARACTERISTICS FOR AN AVCO LYCOMING TIO-540-J2BD ENGINE WITH DIFFERENT FUEL SCHEDULE ADJUSTMENTS--SEA LEVEL HOT DAY--TABLE 4 MAXIMUM FIVE-MODE LTO CYCLE

emission level below the proposed federal standard. It should be noted here that this engine could not be leaned-out below an F/A=0.088 because limited acceleration tests demonstrated that this engine could not accelerate from taxi to takeoff if fuel flows were below 22 lb/hr.

Simultaneously, leaning-out both the taxi and approach modes will result in additional improvements in CO emissions. In the case of operating the engine at production rich limits for takeoff and climb while operating taxi and approach at F/A of 0.088 and 0.067, respectively, the total five-mode LTO cycle CO emission level will be reduced approximately 97 percent as shown in figure 12.

Additional improvements in the total five-mode LTO cycle for CO emissions can be achieved, as shown in figure 12, if the engine is adjusted to operate at "best power" fuel-air ratios in the climb mode while operating the approach and taxi modes at F/A of 0.088 and 0.067, respectively.

The preceding evaluation of CO emissions characteristics was based on the LTO cycle defined by table 5. However, the EPA five-mode LTO cycle defined by table 2 implies that the climb mode power levels range from 75 to 100 percent. The exhaust emissions produced will be drastically affected (see figures 14, 15, and 16). Examination of the measured data produced at NAFEC shows that there is a significant difference in each engine's total LTO cycle emissions output when climbing at 100 percent power compared to climbing at 75-percent power. When one considers the following safety considerations: (1) sea level, hot-day takeoff requirements with an aircraft at heavy gross weight and (2) altitude hot-day takeoff requirements with an aircraft at heavy gross weight, it would appear that the EPA 0.042 limit for CO is not realistic and cannot be complied with unless engine operational and safety limits are totally ignored. A proposed limit of 0.075 lb/cycle/rated BHP appears to be more readily achievable and realistic.

Table 6 provides a summary of the NAFEC data which indicates what levels of improvement in CO emissions can be achieved by applying simple fuel management techniques (leaning-out by mixture control manipulations), albeit with drastically reduced margins between actual measured maximum cylinder head temperature (CHT), the maximum CHT limit, and maximum service life limits established by reference 16.

Example: Consider the engine installed in a sea level (SL.) propeller stand and operating with cooling air at a $\Delta P = 6.0$ inH_2O and the following critical test conditions:

1. Ambient conditions (pressure, temperature, and density)--SL. standard day
2. Fuel schedule--production rich setting
3. Power setting--100%
4. Measured max. CHT--420° F
5. Max. CHT limit--475° F
6. Margin--5 minus 4--55° F

TABLE 6. SUMMARY OF EXHAUST EMISSIONS (CO) REDUCTION POSSIBILITIES FOR AN AVCO LYCOMING TIO-540-J2BD ENGINE--SEA LEVEL STANDARD DAY (EXCEPT AS NOTED--COOLING AIR ΔP=6.0 inH_2O

	Mode	F/A	CO lb/Mode	Max. CHT-°F	F/A	CO lb/Mode	Max. CHT-°F	Max. CHT-°F	Max. Limit CHT-°F
1	Taxi	0.1052	9.200		0.0880	5.600			
2	Takeoff (100%)	0.1024	2.005	420	0.0900	1.575	475	475	475
3	Climb (100%)	0.1024	33.417	420	0.0900	26.250	475	475	475
4	Approach	0.0921	12.250	320	0.0670	1.700	385	390	475
5	lb/Cycle		56.872			35.125			
6	lb/Cycle/RBHP		0.1625			0.1004			
7	Federal Limit		0.042			0.042			
8	Diff. = 6 - 7		0.1205			0.0584			
9	(8 + 7) x 100		286.9			138.9			
10	% of STD = 9 + 100		386.9			238.9			
				This column for SL. Standard Day			This column for SL. Standard Day	This column for SL. Hot Day	
11	Taxi	0.1052	9.200		0.0880	5.600			
12	Takeoff (100%)	0.1024	2.005	420	0.0900	1.575	475	475	475
13	Climb (75 - 80%)	0.1050	25.000	365	0.0775	11.083	450	475	475
14	Approach	0.0921	12.250	320	0.0670	1.700	385	390	475
15	lb/Cycle		48.455			19.958			
16	lb/Cycle/RBHP		0.1384			0.0570			
17	Federal Limit		0.042			0.042			
18	Diff. = 16 = 17		0.0964			0.0150			
19	(18 + 17) x 100		229.6			38.7			
20	% of STD = 19 + 100		329.6			135.7			

If this engine fuel schedule setting is adjusted to best power (all other parameters constant based on above conditions), the following changes take place:

1. CO emissions are improved approx. 193% (nominal)
2. Measured max. CHT increases 9.5% (from 420° F to 460° F)
3. Max. CHT limit--475° F
4. Margin--(3) minus (2) = 15° F
5. Reduction in margin (max CHT)--(40 ÷ 55) x 100 = 72.7%

Now, if we apply the above results to a SL. hot-day condition, we arrive at the following results:

Production Rich Limit Schedule (100% power)

1. Ambient conditions--SL. hot day (95° F)
2. Fuel schedule--production rich setting
3. Power setting--100% (nominal)
4. Measured max. CHT--440° F
5. Max. CHT limit--475° F
6. Margin--(5) minus (4) = 35° F

Best Power Fuel Schedule (100% Power)

1. Ambient conditions--SL. hot day
2. Fuel schedule--best power fuel schedule (F/A = 0.0900)
3. Power setting--100% (nominal)
4. Measured max. CHT--475° F
5. Max. CHT limit--475° F
6. Margin--(5) minus (4) = 0° F
7. Reduction in margin (max. CHT)--(35 ÷ 35) x 100 = 100.0%

EFFECTS OF LEANING-OUT ON HC EMISSIONS. The test data show that the Lycoming engine can be leaned-out in the taxi mode to reduce the unburned hydrocarbon emissions, but not below the federal standard (figure 12). Additional leaning-out in the approach and climb modes provides the added improvements needed to reduce HC emission levels below the federal standard.

EFFECTS OF LEANING-OUT ON NO_x EMISSIONS. Oxides of nitrogen emissions are not improved as a result of applying lean-out adjustments to the fuel metering devices. In fact, the NO_x levels are at their lowest when the engine is operating full rich as shown in figure 11.

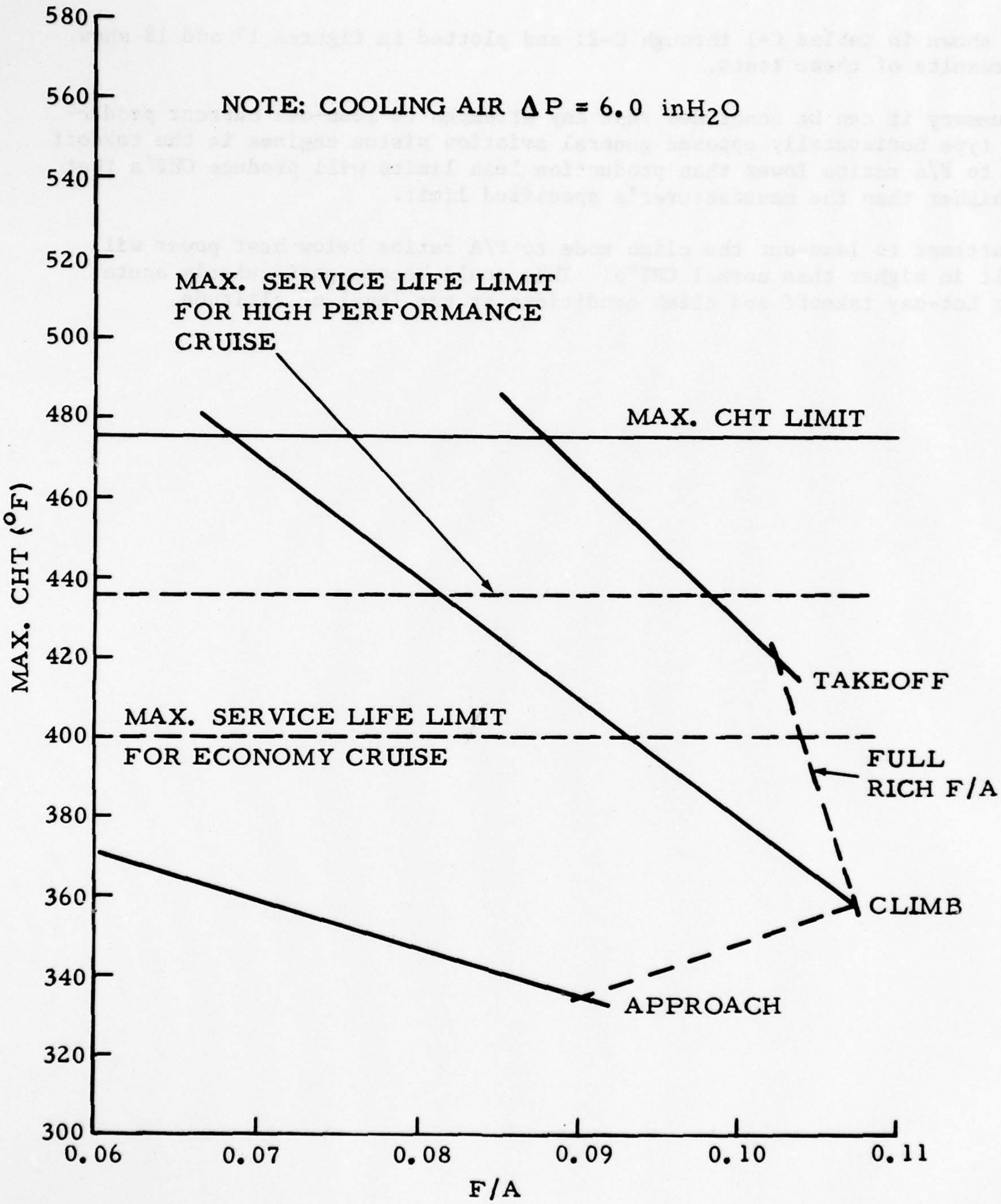
EFFECTS ON ALLOWABLE MAXIMUM CYLINDER HEAD TEMPERATURE. One of the major problems that occurs as an effect of leaning-out general aviation piston engines in order to improve emissions is the increase or rise in maximum cylinder head temperatures.

Most of the small general aviation aircraft are designed to operate with cooling air pressure differentials of 4.0 inH_2O or less. The tests conducted with the AVCO Lycoming TIO-540-J2BD engine utilized 6.0 inH_2O as the basic cooling flow condition. This engine is usually installed in larger general aviation aircraft of the twin-engine type.

Data shown in tables C-1 through C-21 and plotted in figures 17 and 18 show the results of these tests.

In summary it can be concluded that any attempts to lean-out current production type horizontally opposed general aviation piston engines in the takeoff mode to F/A ratios lower than production lean limits will produce CHT's that are higher than the manufacturer's specified limit.

Any attempt to lean-out the climb mode to F/A ratios below best power will result in higher than normal CHT's. This could become particularly acute under hot-day takeoff and climb conditions at sea level or altitude.



79-36-17

FIGURE 17. SEA LEVEL STANDARD DAY MAXIMUM CYLINDER HEAD TEMPERATURES FOR DIFFERENT POWER CONDITIONS AND VARYING FUEL-AIR RATIOS--AVCO LYCOMING TIO-540-J2BD ENGINE

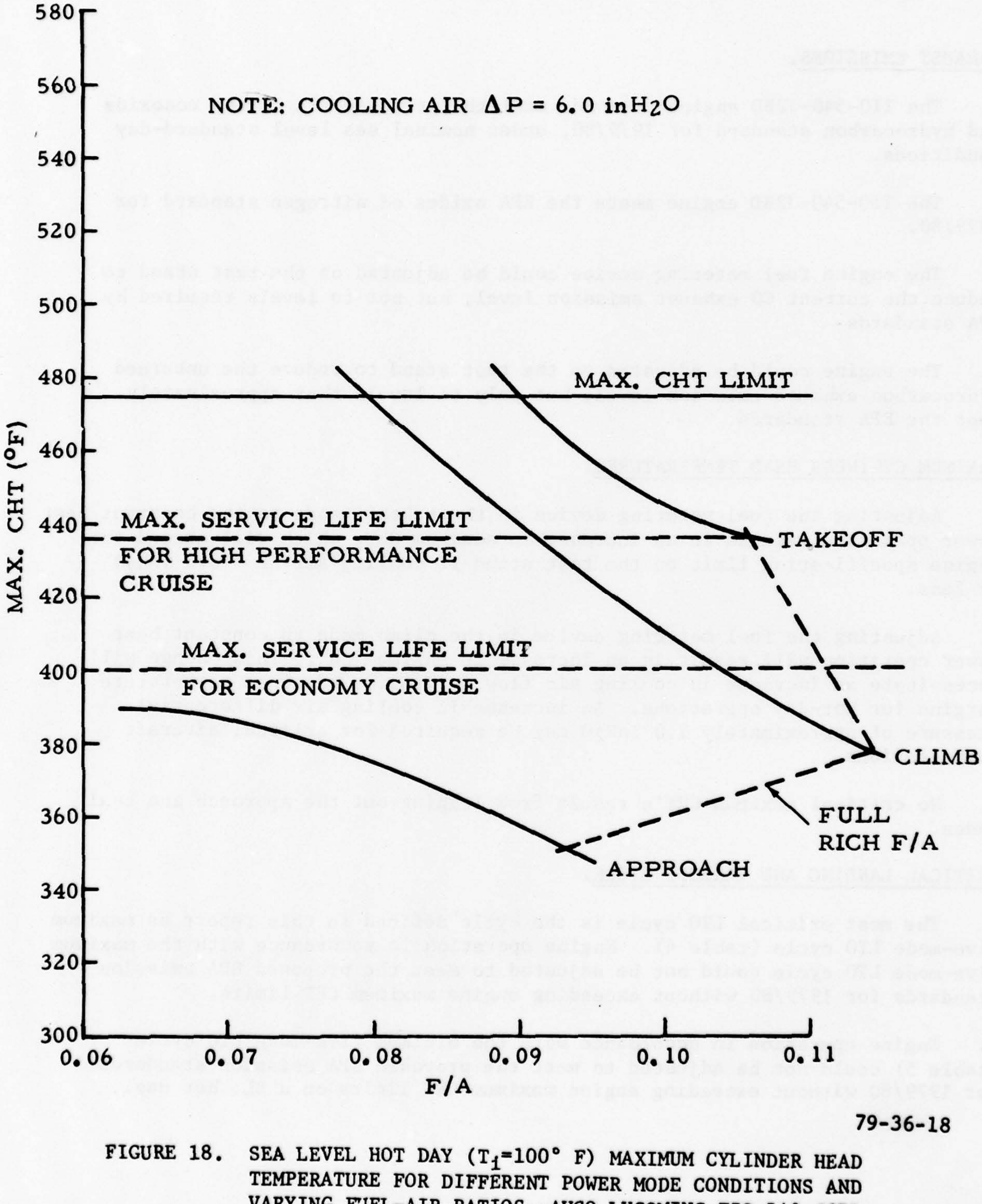


FIGURE 18. SEA LEVEL HOT DAY (T_1=100° F) MAXIMUM CYLINDER HEAD TEMPERATURE FOR DIFFERENT POWER MODE CONDITIONS AND VARYING FJEL-AIR RATIOS--AVCO LYCOMING TIO-540-J2BD ENGINE

SUMMARY OF RESULTS

EXHAUST EMISSIONS.

1. The TIO-540-J2BD engine does not meet the proposed EPA carbon monoxide and hydrocarbon standard for 1979/80, under nominal sea level standard-day conditions.

2. The TIO-540-J2BD engine meets the EPA oxides of nitrogen standard for 1979/80.

3. The engine fuel metering device could be adjusted on the test stand to reduce the current CO exhaust emission level, but not to levels required by EPA standards.

4. The engine could be adjusted on the test stand to reduce the unburned hydrocarbon exhaust emission level, but only to levels that approximately meet the EPA standards.

MAXIMUM CYLINDER HEAD TEMPERATURES.

1. Adjusting the fuel metering device in the takeoff mode to the constant best power operation results in an increase in maximum CHT, which will exceed the engine specification limit on the test stand if cooling air $\Delta P = 6.0$ inH_2O or less.

2. Adjusting the fuel metering device in the climb mode to constant best power operation will result in an increase in maximum CHT. This change will necessitate an increase in cooling air flow to provide adequate temperature margins for hot-day operations. An increase in cooling air differential pressure of approximately 1.0 inH_2O may be required for critical aircraft installations.

3. No critical maximum CHT's result from leaning-out the approach and taxi modes.

CRITICAL LANDING AND TAKEOFF CYCLE.

1. The most critical LTO cycle is the cycle defined in this report as maximum five-mode LTO cycle (table 4). Engine operation in accordance with the maximum five-mode LTO cycle could not be adjusted to meet the proposed EPA emission standards for 1979/80 without exceeding engine maximum CHT limits.

2. Engine operation in accordance with the minimum five-mode LTO cycle (table 5) could not be adjusted to meet the proposed EPA emission standards for 1979/80 without exceeding engine maximum CHT limits on a SL. hot day.

CONCLUSIONS

The following conclusions are based on the testing accomplished with the AVCO Lycoming TIO-540-J2BD engine.

1. The single use of simple fuel management adjustments (altering of fuel schedule) does not allow safe reduction of exhaust emissions of the test engine, the AVCO Lycoming TIO-540-J2BD. In conjunction with other data, references 12, 13, 14, and 15, this appears to be a valid general conclusion for typical light-aircraft piston engines.

2. The test data indicate that fuel management adjustments must be combined with engine/nacelle cooling modifications before safe, low-emission aircraft/engine combination can be achieved.

3. The EPA CO limit of 0.042 lb/cycle/rated BHP is not achievable when take-off and climb requirements are impacted by aircraft heavy gross weight and the need to pay close attention to CHT limitations.

4. Based on an assessment of the maximum five-mode LTO cycle (table 4) test data, it is concluded that the following standard changes should be made to the proposed EPA emission standards:

Proposed EPA Standard for 1979/190 (Reference 1) (lb/cycle/rated BPH)	Proposed Change to the 1979/80 Standard (lb/cycle/rated BHP)
CO Standard 0.042	0.075
HC Standard 0.0019	0.0025
NO_x Standard 0.0015	0.0015

5. To avoid CHT problems in the takeoff mode (100-percent power), it is advisable not to adjust the fuel metering device. Engine operation in this mode should continue to be accomplished within current production rich/lean limits.

6. The test procedures (baseline and lean-out tests) and test techniques used to evaluate the exhaust emissions characteristics of this engine appeared to be satisfactory for sea-level propeller stand test work.

7. The instrumentation defined in this report proved to be satisfactory throughout the conduct of tests performed with this engine.

REFERENCES

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3. Salmon, R. F. and Imbrogno S., Measurement and Testing Problems Experienced During FAA's Emissions Testing of General Aviation Piston Engines, Aircraft Piston Engine Exhaust Emissions Symposium, Lewis Research Center, Cleveland, Ohio, September 14-15, 1976.

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8. Guide to Aviation Products, Humble Oil and Refining Company, 1969.

9. NAPTC Fuel Sample Analysis -- 100/130 Octane Aviation Gasoline, 1976.

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16. Avco Lycoming Division, Fuel Mixture Leaning Procedures, Service Instruction No. 1094C, January 31, 1969.

APPENDIX A

FUEL SAMPLE ANALYSIS

COMBUSTIBLE ELEMENTS IN FUELS (AVIATION FUEL).

1. Carbon and hydrogen are the predominant combustible elements in fuels (aviation type), with small amounts of sulphur as the only other fuel element.

2. Liquid fuels are mixtures of complex hydrocarbons.

3. For combustion calculations, gasoline or fuel oil can be assumed to have the average molecular formula C_8H_{17}.

Note: The Exxon® data presented in table A-1 may be found in reference 8.

TABLE A-1. TYPICAL SPECIFICATIONS FOR AVIATION FUELS

Item	D910-76 Grade 100/130	Exxon Aviation Gas 100/130	D910-70 Grade 115/145	Exxon Aviation Gas 115/145
Freezing Point, °F	-72 Max.	Below -76	-76 Max.	Below -76
Reid Vapor Press., PSI	7.0 Max.	6.8	7.0 Max.	6.8
Sulfur, % by Weight	0.05 Max.	0.02	0.05 Max.	0.02
Lower Heating Value, BTU/lb	18,720 Min.		18,800 Min.	
Heat of Comb. (NET). BTU/lb		18,960		19,050
Distillation, %Evaporated				
At 167° F (Max.)	10	22	10	21
At 167° F (Min.)	40		40	
At 221° F (Max.)	50	76	50	62
At 275° F (Max.)	90	97	90	96
Distillation End Point	338° F Max.		338° F Max.	
Final Boiling Point °F		319		322
Tel Content, ML/U.S. Gal.	4.0 Max.	3.9	4.6 Max.	4.5
Color	Green	Green	Purple	Purple

4. NAFEC used 100/130 (octane rated) aviation gasoline for the piston engine emission tests. The following analysis of a typical fuel sample (table A-2) made at the U.S. Naval Air Propulsion Test Center (NAPTC), Trenton, N.J. (reference 9).

TABLE A-2. ANALYSIS OF NAFEC FUEL SAMPLE, 100/130 FUEL

Item	NAFEC Sample 100/130	Grade 100/130(MIL-G-5572E) Spec Limits Min.		Max.
Freezing Point, °F	Below -76° F			-76
Reid Vapor Press., PSI	6.12	5.5		7.0
Sulfur % By Weight	0.024			0.05
Lower Heating Value BTU/lb		18,700		
Heat of Comb. (NET) BTU/lb	18,900			
Distillation, % Evaporated			Distillation % Evaporation	
At 158° F	10			
At 167° F (Min.)		167° F	10	
At 167° F (Max.)			40	167° F
At 210° F	40			
At 220° F	50			
At 221° F		221° F	50	
At 242° F	90			
At 275° F		275° F	90	
Distillation End Point	313° F			338° F
Specific Gravity @60° F	0.7071	Report		Report
API Gravity @60° F	68.6		No Limit	
Tel Content, ML/U.S. Gal.	1.84			4.60

Computation for the fuel hydrogen-carbon ratio is based on the fuel net heating value, h_f, equal to 18,900 BTU/lb and figure A-1.

$C/H = 5.6$
$C = 12.011$
$C_8 = 8 \times 12.011 = 96.088$
$H_y = (96.088) \div 5.6 = 17.159$
$H = 1.008$
$Y = (17.159) \div 1.008 = 17.022$ Use $Y = 17$

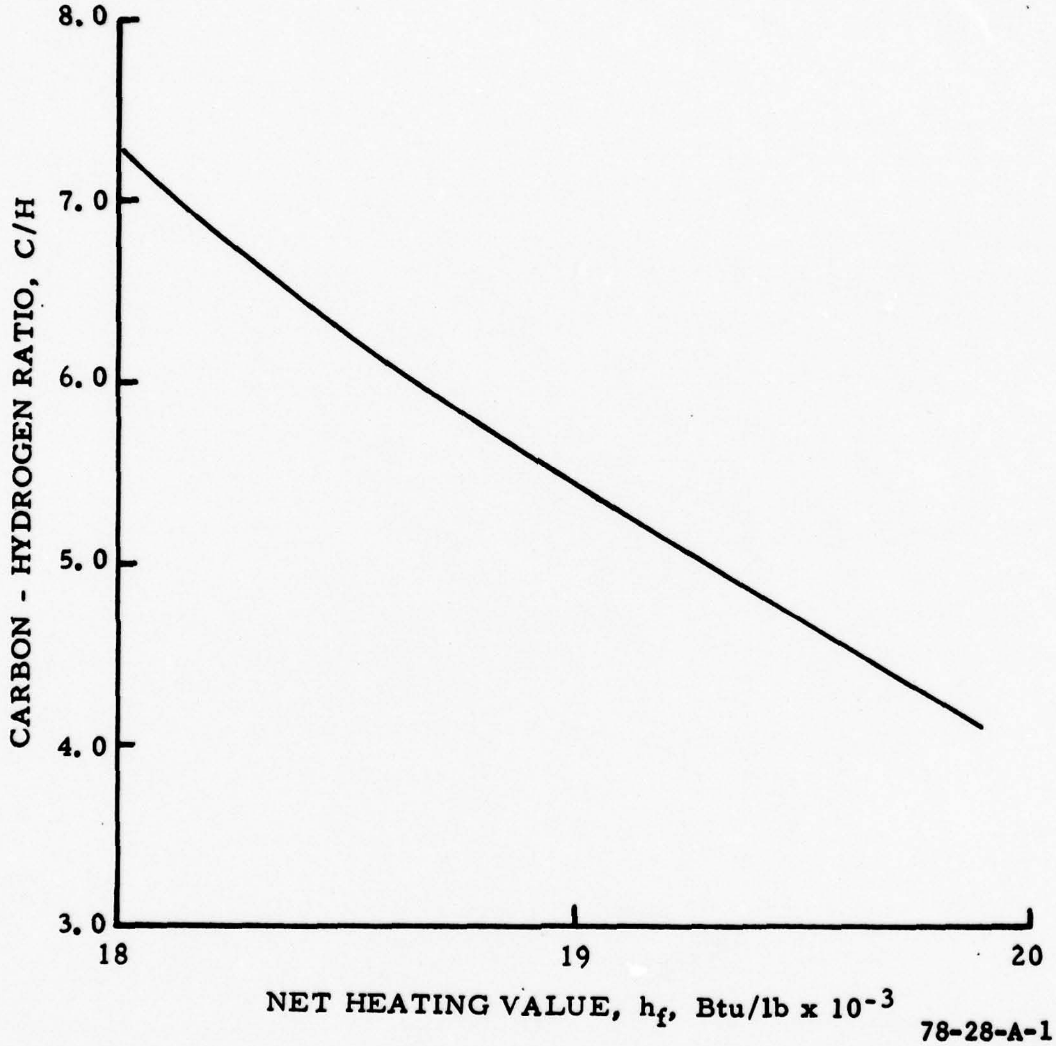

FIGURE A-1. NET HEATING VALUE FOR AVIATION GASOLINE AND CARBON-HYDROGEN RATIO CORRELATION

APPENDIX B

COMPOSITION OF AIR (GENERAL PROPERTIES)

1. Dry air is a mixture of gases that has a representative volumetric analysis in percentages as follows:

Oxygen (O_2)--20.99%
Nitrogen (N_2)--78.03%
Argon (A)--0.94% (Also includes traces of the rare gases neon, helium, and krypton)
Carbon Dioxide (CO_2)--0.03%
Hydrogen (H_2)--0.01%

2. For most calculations it is sufficiently accurate to consider dry air as consisting of:

O_2 = 21.0%
N_2 = 79.0% (including all other inert gases)

3. The moisture or humidity in atmospheric air varies over wide limits, depending on meteorological conditions, its presence in most cases simply implies an additional amount of essentially inert material.

Note: *Information* given in items 1, 2, and 3 is recommended for computation purposes (reference 4, 5, 10, and 11).

TABLE B-1. MASS ANALYSIS OF PURE DRY AIR

Gas	Volumetric Analysis %	Mole Fraction	Molecular Weight	Relative Weight
O_2	20.99	0.2099	32.00	6.717
N_2	78.03	0.7803	28.016	21.861
A	0.94	0.0094	39.944	0.376
CO_2	0.03	0.0003	44.003	0.013
Inert Gases	0.01	0.0001	48.0	0.002
	100.00	1.000		28.969 = M for air

4. The molecular weight of the <u>apparent nitrogen</u> can be similarly determined by dividing the total mass of the inert gases by the total number of moles of these components:

$$M_{\substack{\text{Apparent}\\\text{Nitrogen}}} = \frac{2225}{79.01} = 28.161$$

5. This appendix advocates the term nitrogen as referring to the entire group of inert gases in the atmosphere and therefore the molecular weight of 28.161 will be the correct value (rather than the value 28.016 for pure nitrogen).

6. In combustion processes the active constituent is oxygen (O_2), and the apparent nitrogen can be considered to be inert. Then for every mole of oxygen supplied, 3.764 moles of apparent nitrogen accompany or dilute the oxygen in the reaction:

$$\frac{79.01}{20.99} = 3.764 \frac{\text{Moles Apparent Nitrogen}}{\text{Mole Oxygen}}$$

7. The information given in items 4, 5, and 6 is recommended for computational purposes in reference 5. Therefore, one mole of air (dry), which is composed of one mole of oxygen (O_2) and 3.764 moles of nitrogen (N_2), has a total weight of 137.998 pounds.

$$(O_2 + 3.764\ N_2) = 137.998$$

This gives the molecular weight of air = 28.97.

APPENDIX C

NAFEC TEST DATA AND WORKING PLOTS FOR ANALYSIS AND EVALUATION OF AVCO LYCOMING TIO-540-J2BD ENGINE

LIST OF ILLUSTRATIONS

LIST OF ILLUSTRATIONS (Continued)

LIST OF ILLUSTRATIONS (Continued)

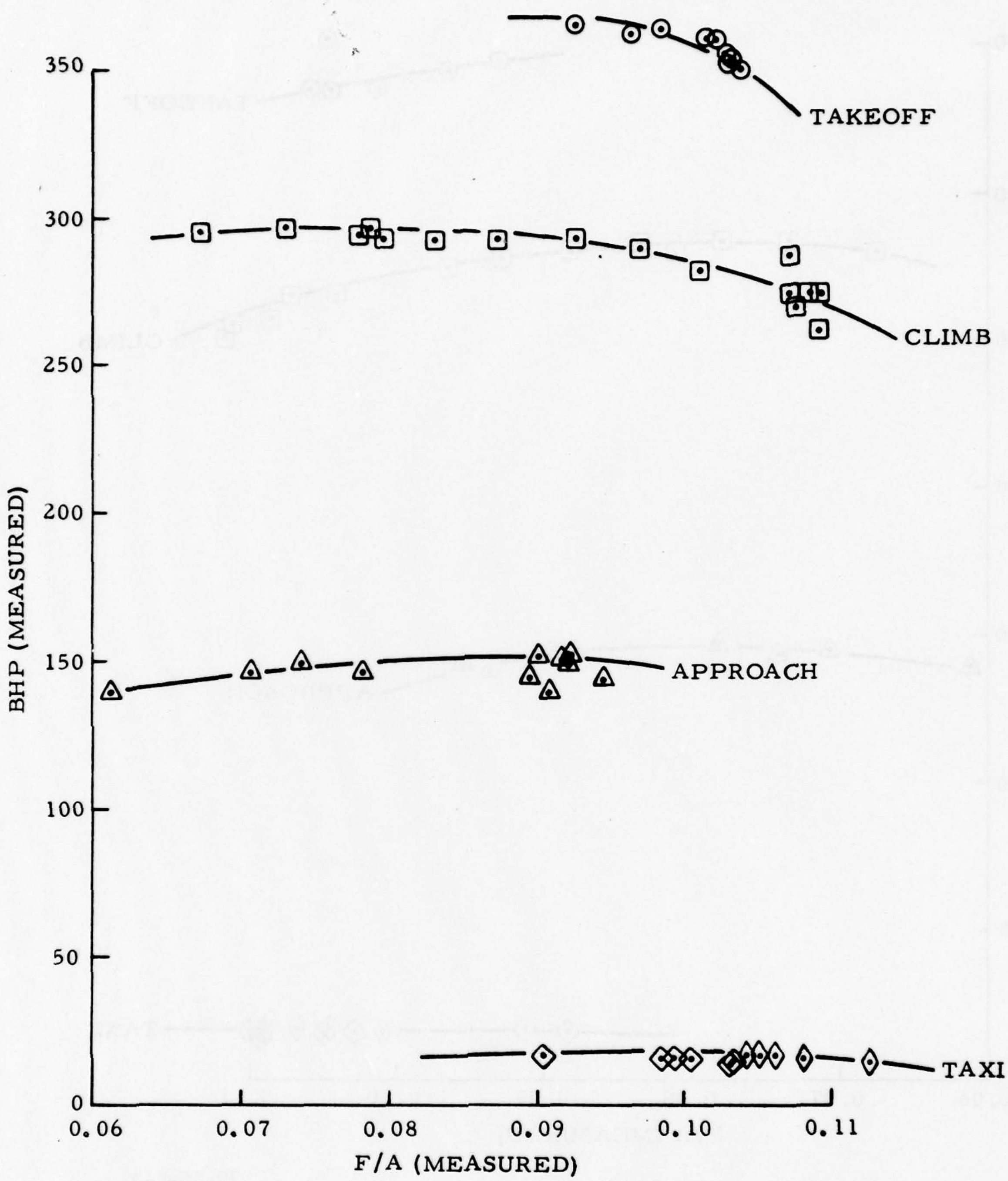

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FIGURE C-1. MEASURED PERFORMANCE--AVCO LYCOMING TIO-540-J2BD ENGINE--TAKEOFF, CLIMB, APPROACH, AND TAXI MODES--NOMINAL SEA LEVEL AIR DENSITY 0.0772 lb/ft^3

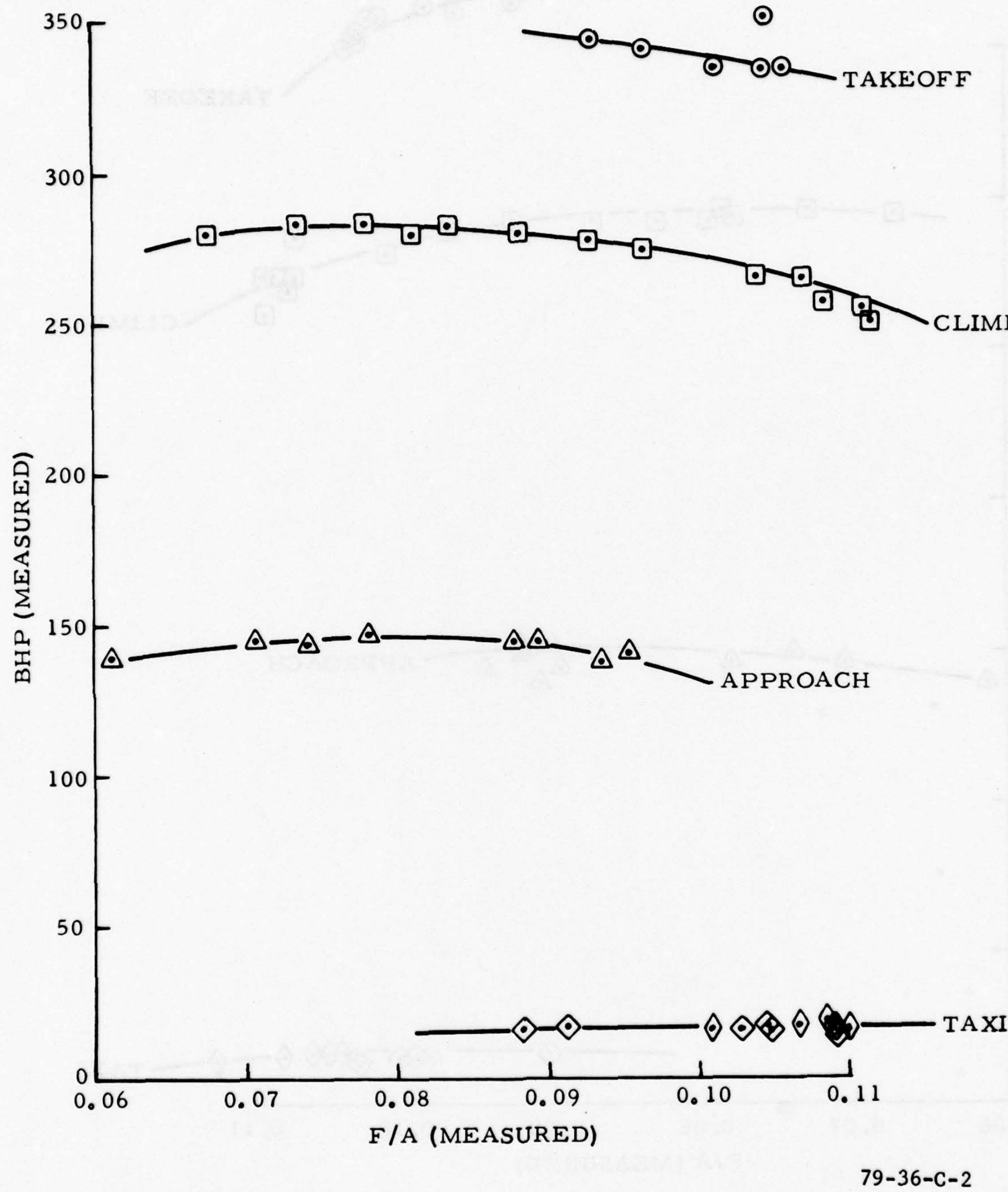

FIGURE C-2. MEASURED PERFORMANCE--AVCO LYCOMING TIO-540-J2BD ENGINE--TAKEOFF, CLIMB, APPROACH, AND TAXI MODES--NOMINAL SEA LEVEL AIR DENSITY 0.0739 lb/ft^3

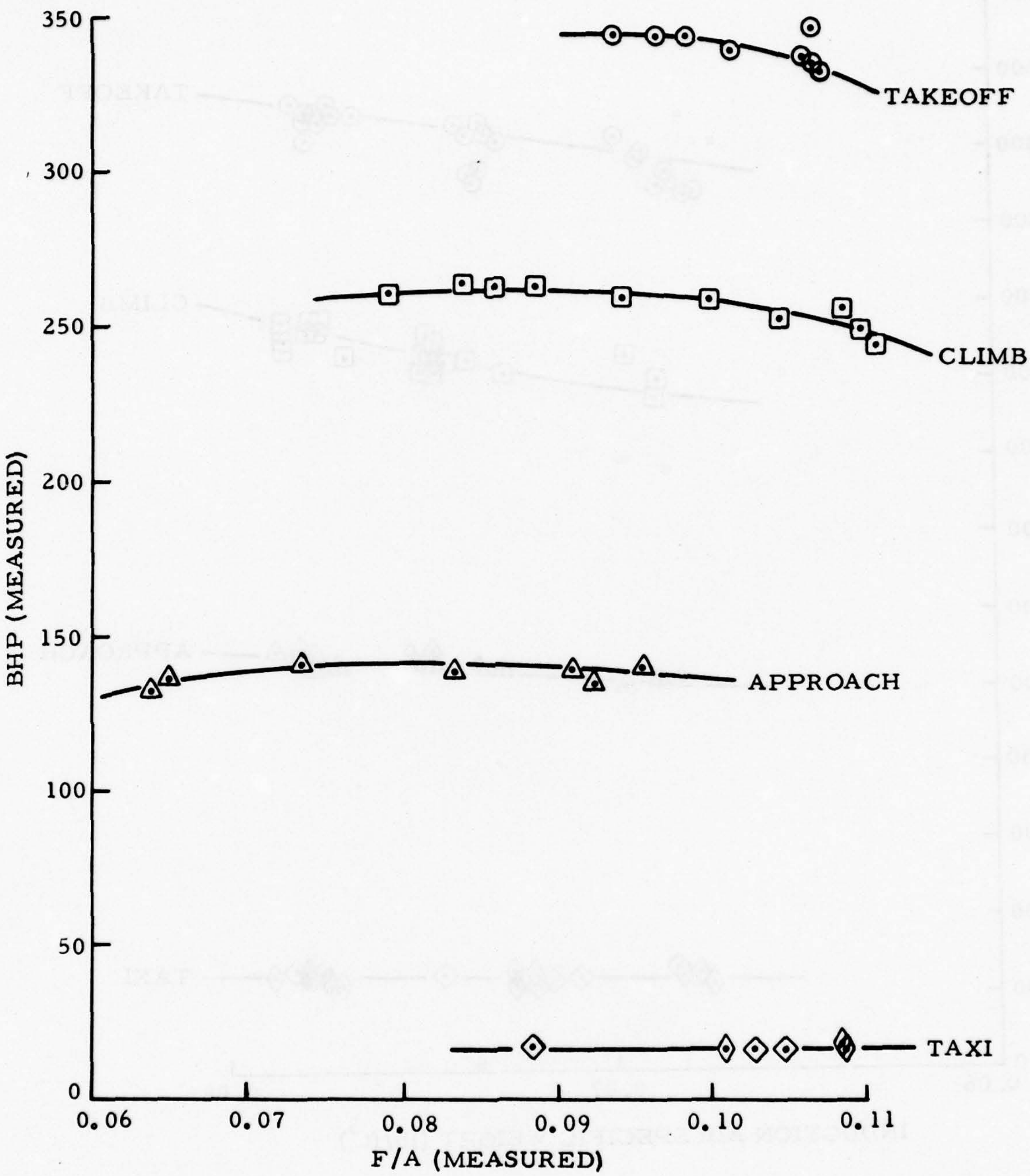

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FIGURE C-3. MEASURED PERFORMANCE--AVCO LYCOMING TIO-540-J2BD ENGINE--TAKEOFF, CLIMB, APPROACH, AND TAXI MODES--NOMINAL SEA LEVEL AIR DENSITY 0.0688 lb/ft^3

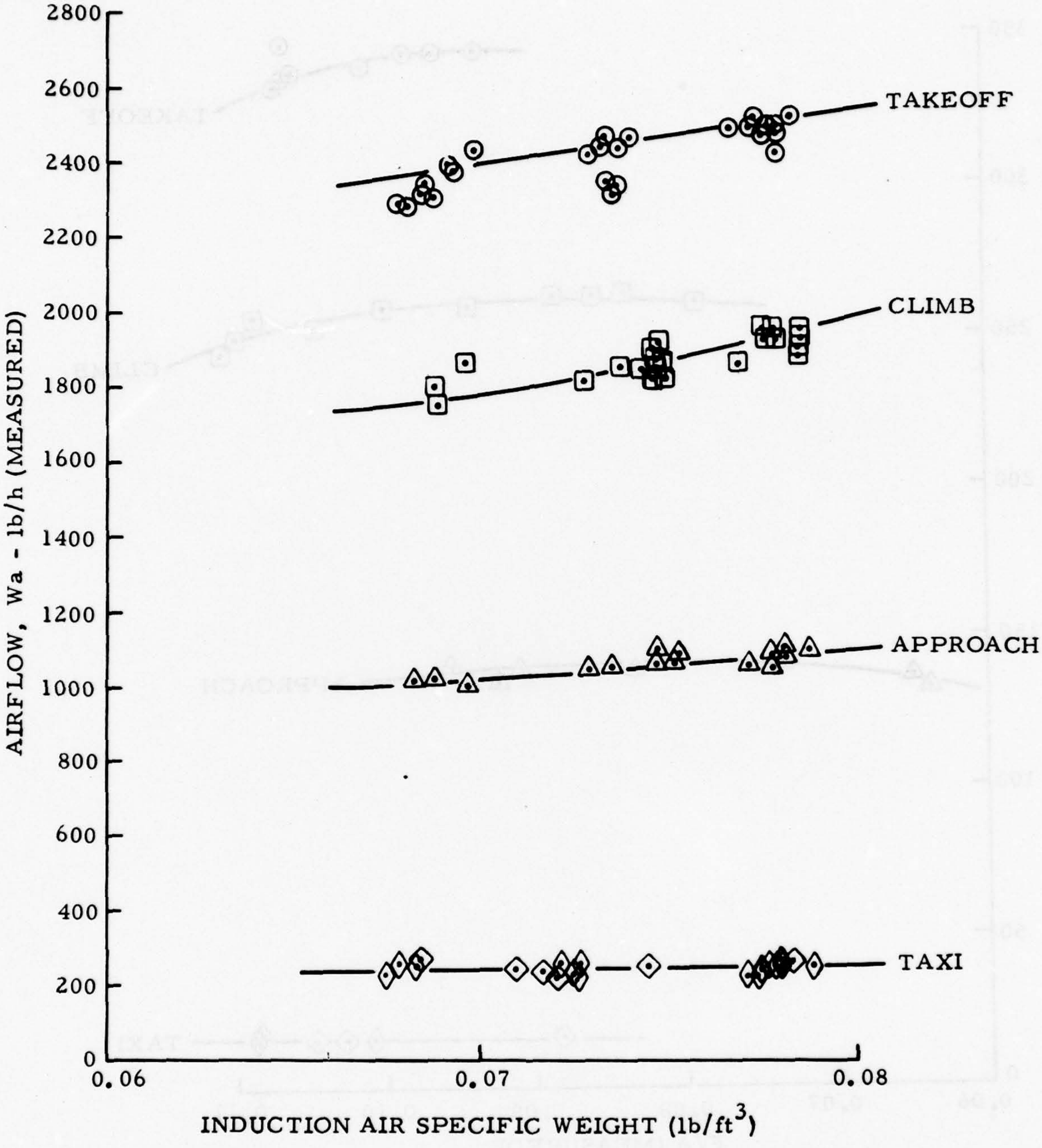

FIGURE C-4. AIRFLOW AS A FUNCTION OF INDUCTION AIR SPECIFIC WEIGHT FOR AN AVCO LYCOMING TIO-540-J2BD ENGINE--NOMINAL SEA LEVEL TEST DATA

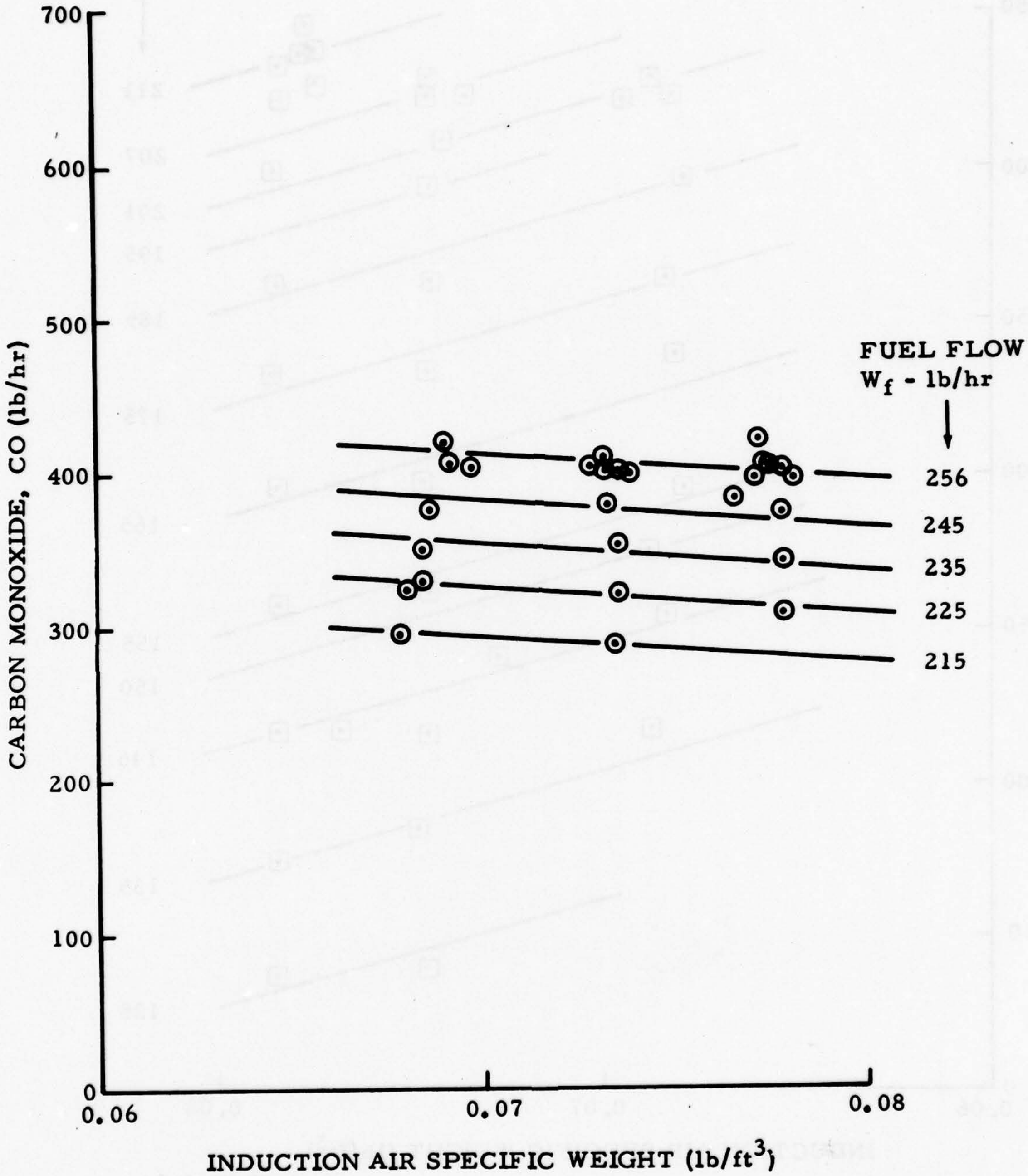

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FIGURE C-5. EXHAUST CARBON MONOXIDE AS A FUNCTION OF INDUCTION AIR SPECIFIC WEIGHT FOR SEVERAL TAKEOFF CONSTANT FUEL FLOW SCHEDULES--AVCO LYCOMING TIO-540-J2BD ENGINE

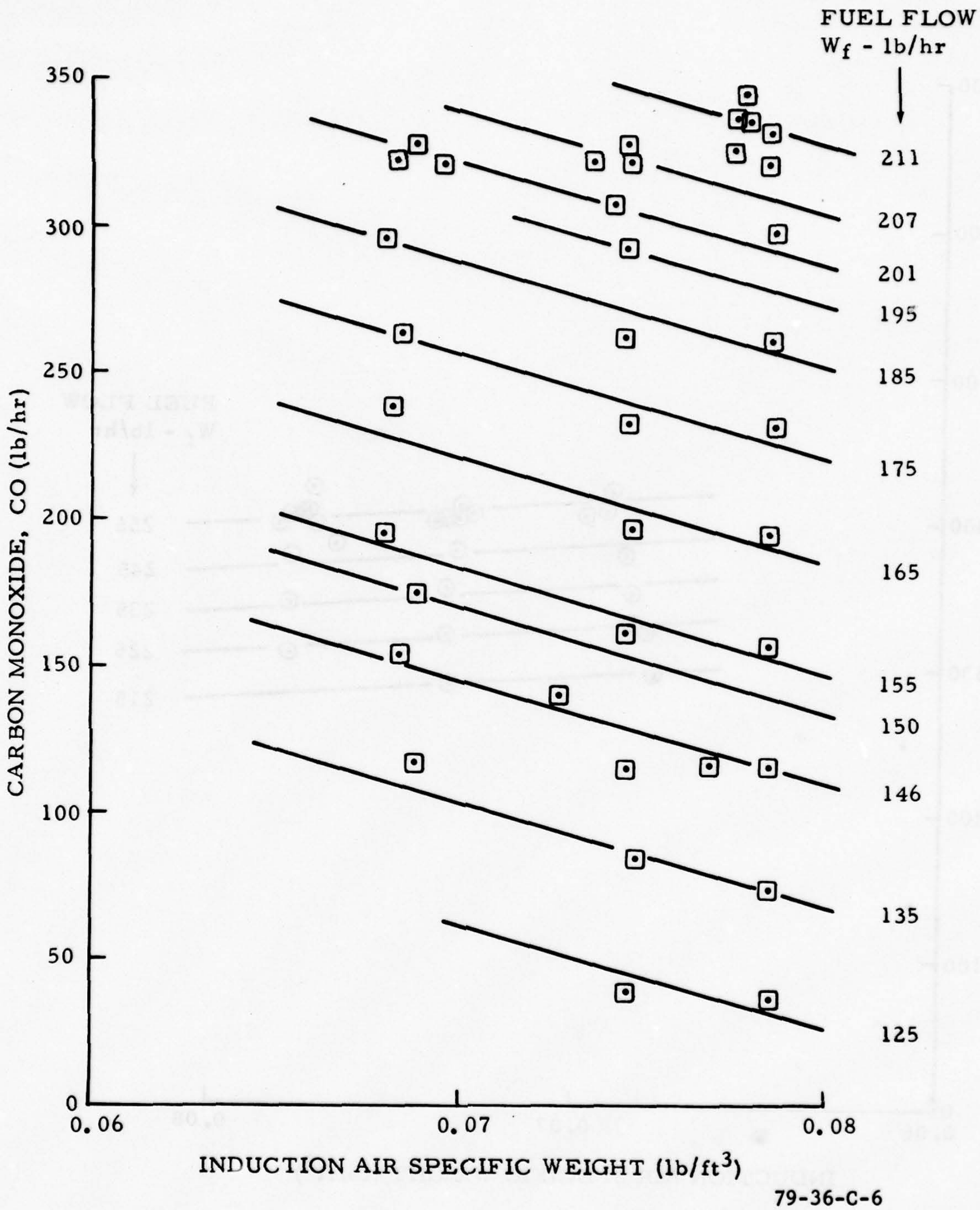
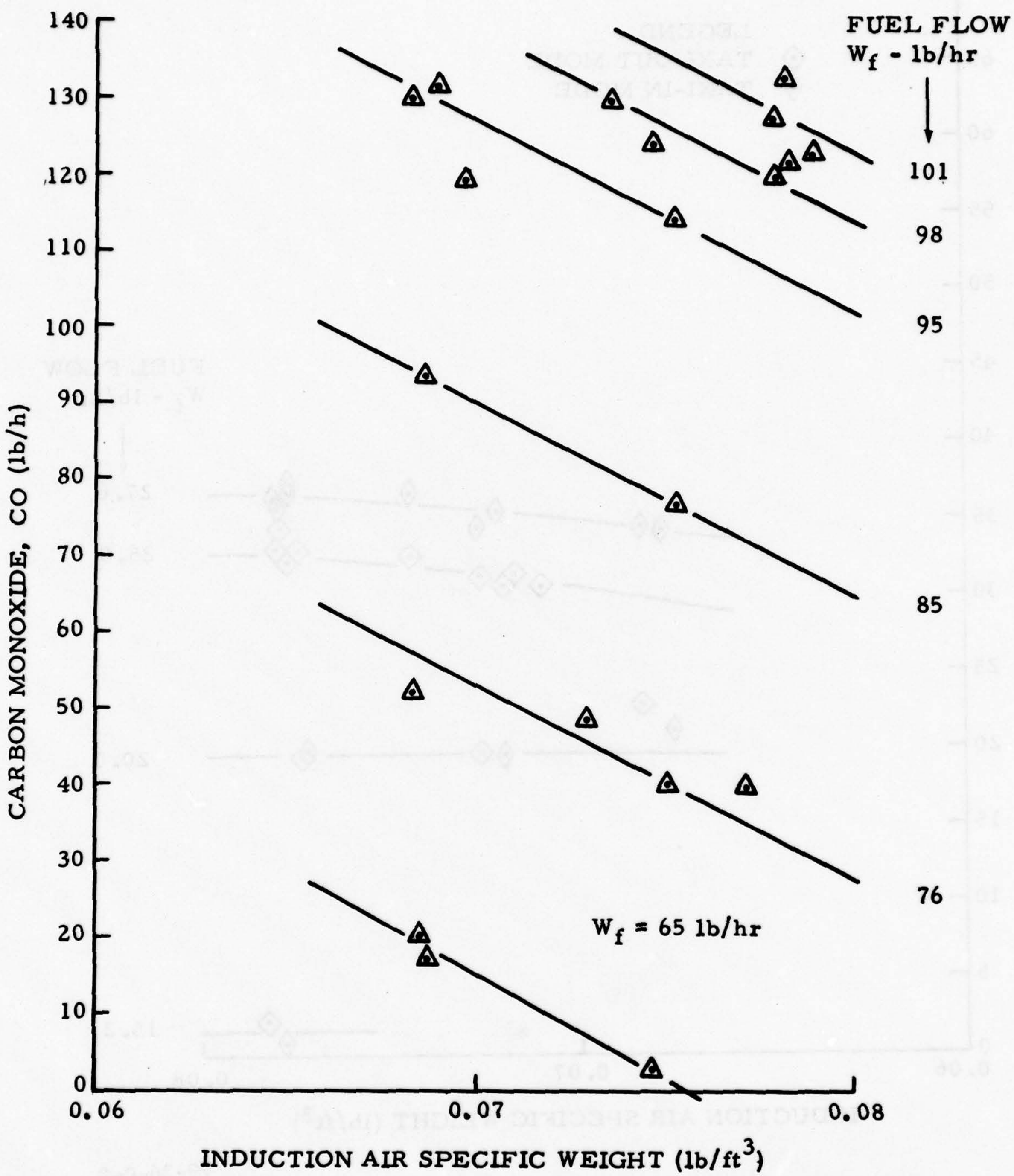


FIGURE C-6. EXHAUST CARBON MONOXIDE AS A FUNCTION OF INDUCTION AIR SPECIFIC WEIGHT FOR SEVERAL CLIMB MODE CONSTANT FUEL FLOW SCHEDULES--AVCO LYCOMING TIO-540-J2BD ENGINE



79-36-C-7

FIGURE C-7. EXHAUST CARBON MONOXIDE AS A FUNCTION OF INDUCTION AIR SPECIFIC WEIGHT FOR SEVERAL APPROACH MODE CONSTANT FUEL FLOW SCHEDULES--AVCO LYCOMING TIO-540-J2BD ENGINE

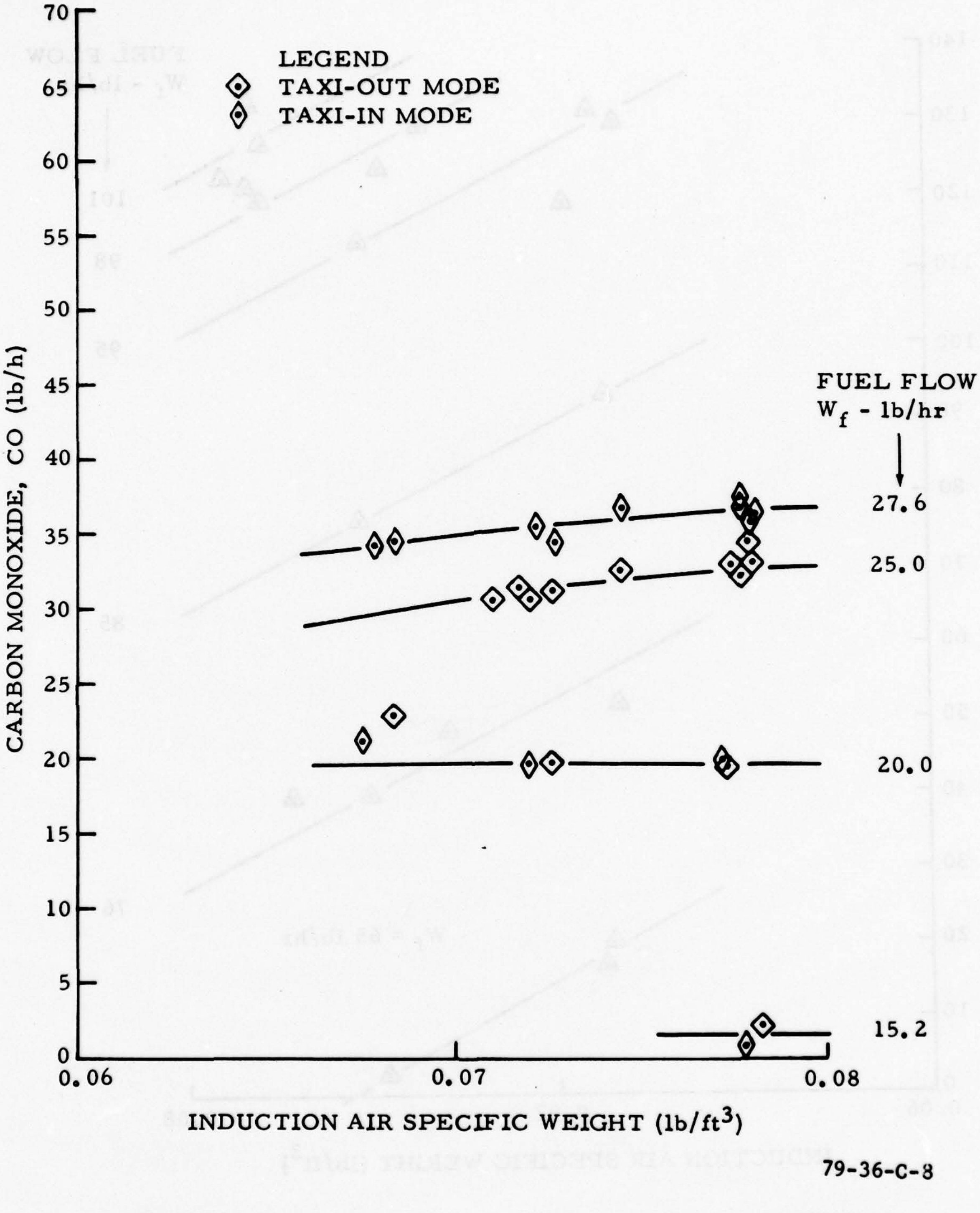


FIGURE C-8. EXHAUST CARBON MONOXIDE AS A FUNCTION OF INDUCTION AIR SPECIFIC WEIGHT FOR SEVERAL TAXI MODE CONSTANT FUEL FLOW SCHEDULES--AVCO LYCOMING TIO-540-J2BD ENGINE

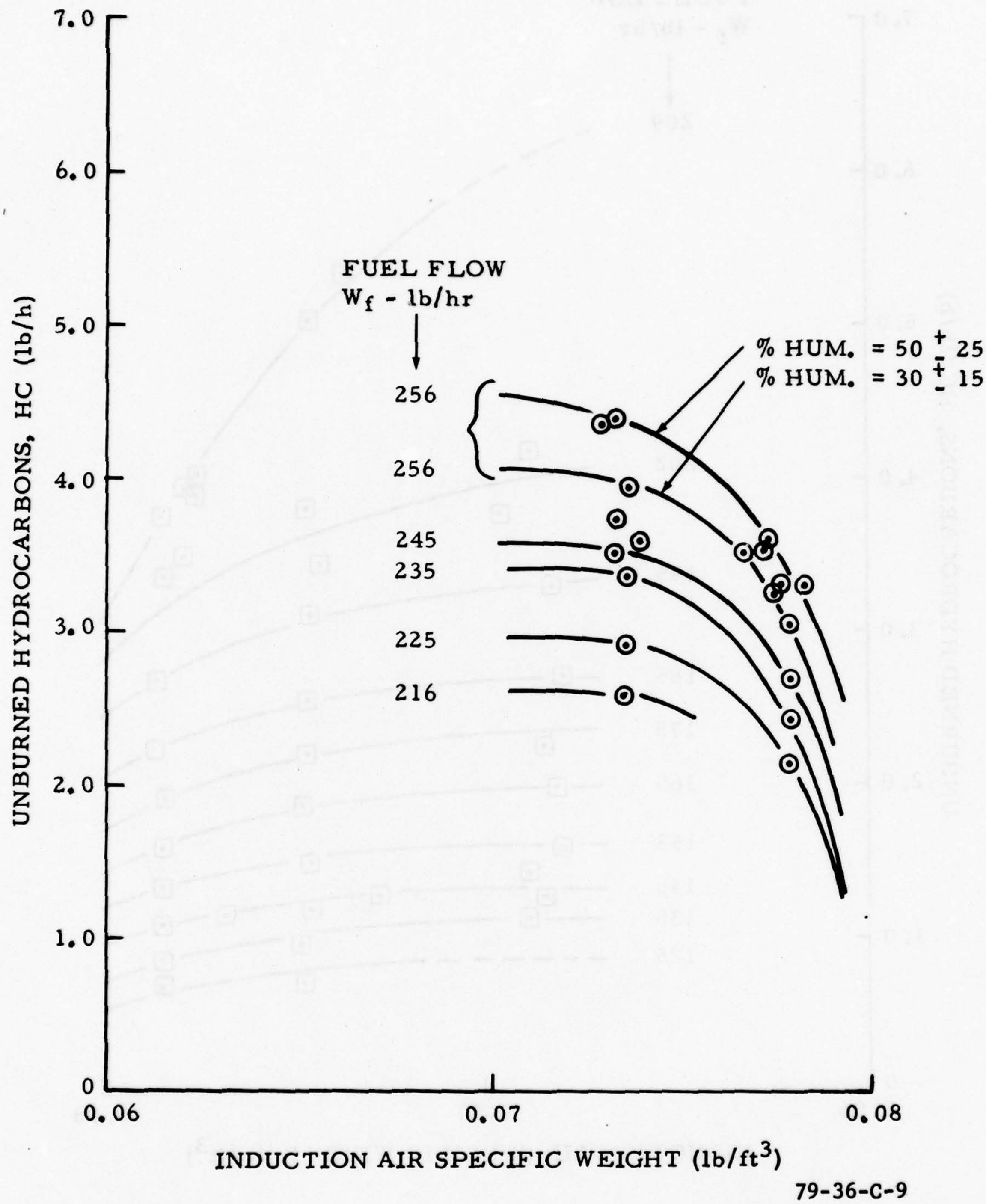


FIGURE C-9. UNBURNED EXHAUST HYDROCARBONS AS A FUNCTION OF INDUCTION AIR SPECIFIC WEIGHT FOR SEVERAL TAKEOFF CONSTANT FUEL FLOW SCHEDULES--AVCO LYCOMING TIO-540-J2BD ENGINE

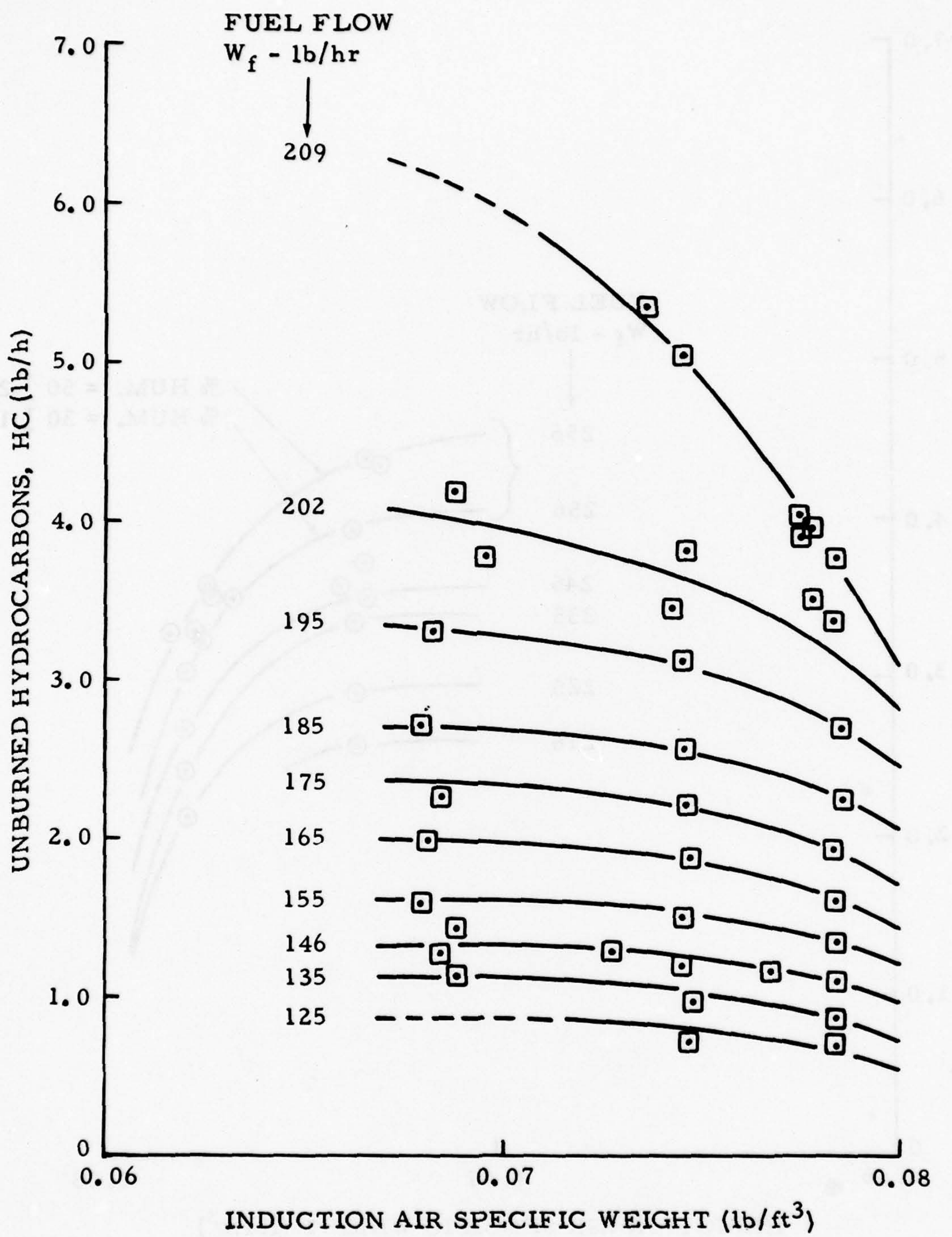


FIGURE C-10. UNBURNED EXHAUST HYDROCARBONS AS A FUNCTION OF INDUCTION AIR SPECIFIC WEIGHT FOR SEVERAL CLIMB MODE CONSTANT FUEL FLOW SCHEDULES--AVCO LYCOMING TIO-504-J2BD ENGINE

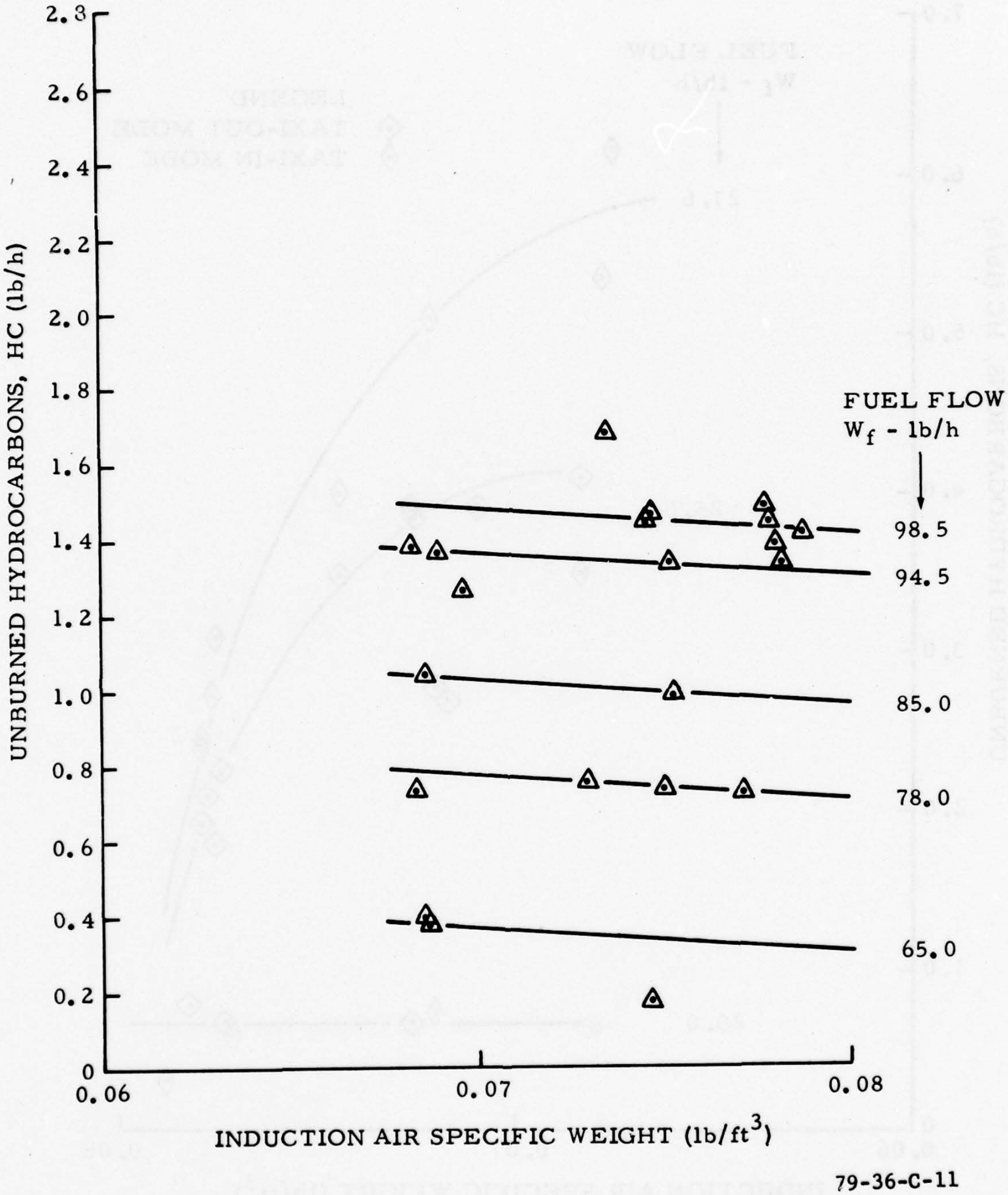


FIGURE C-11. UNBURNED EXHAUST HYDROCARBONS AS A FUNCTION OF INDUCTION AIR SPECIFIC WEIGHT FOR SEVERAL APPROACH MODE CONSTANT FUEL FLOW SCHEDULES--AVCO LYCOMING TIO-540-J2BD ENGINE

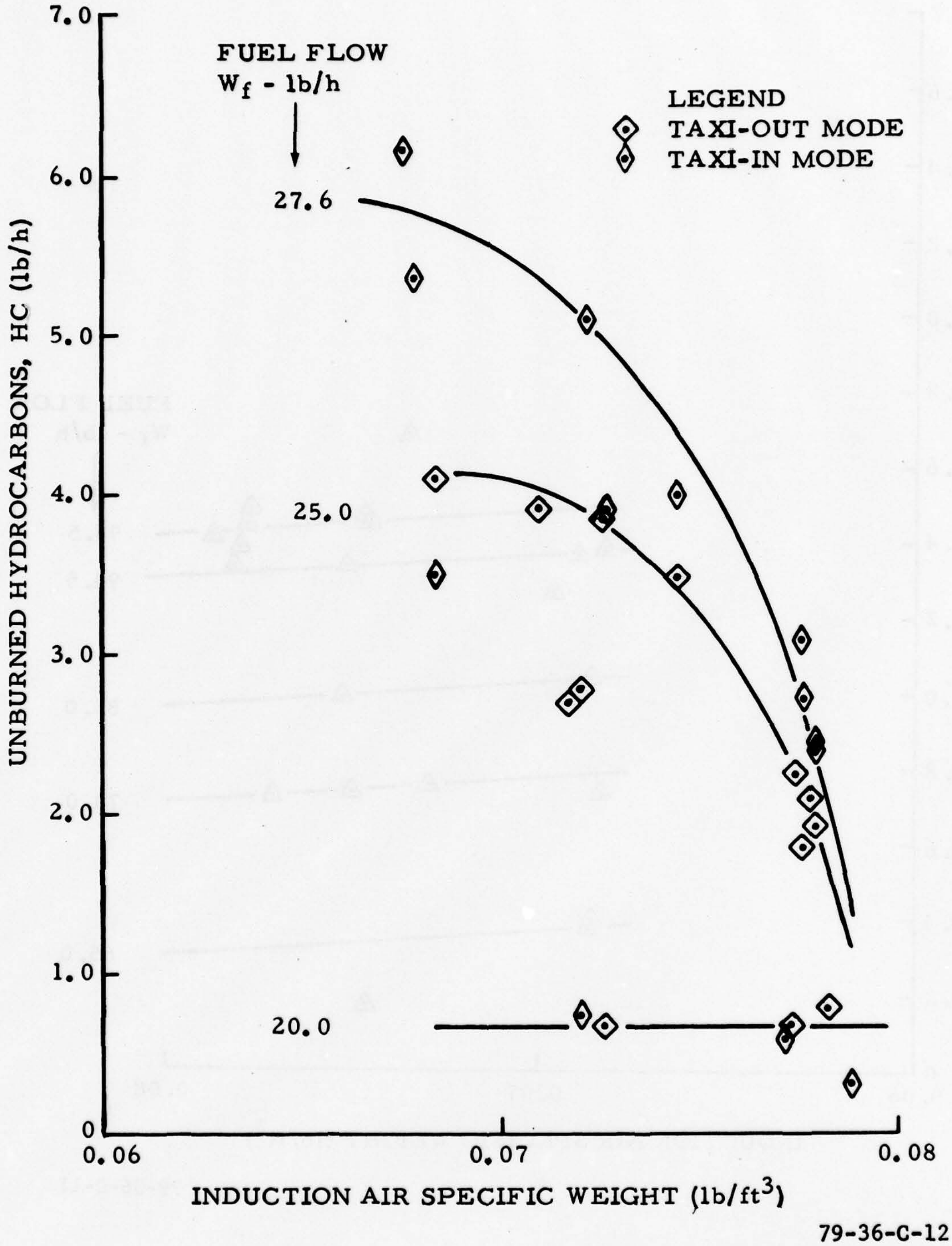


FIGURE C-12. UNBURNED EXHAUST HYDROCARBONS AS A FUNCTION OF INDUCTION AIR SPECIFIC WEIGHT FOR SEVERAL TAXI MODE CONSTANT FUEL FLOW SCHEDULES--AVCO LYCOMING TIO-540-J2BD ENGINE

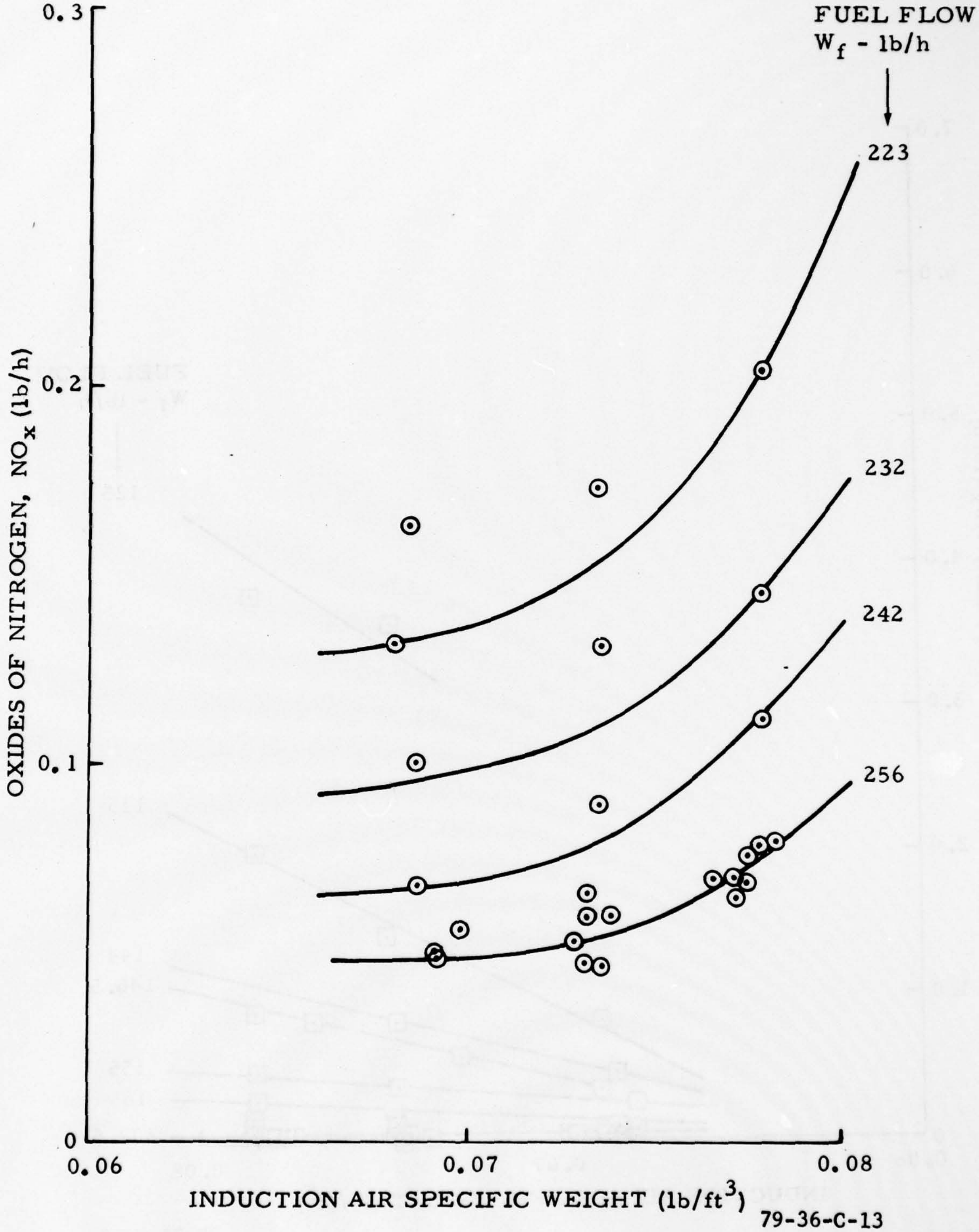


FIGURE C-13. OXIDES OF NITROGEN (NO_x) AS A FUNCTION OF INDUCTION AIR SPECIFIC WEIGHT FOR SEVERAL TAKEOFF CONSTANT FUEL FLOW SCHEDULES--AVCO LYCOMING TIO-540-J2BD ENGINE

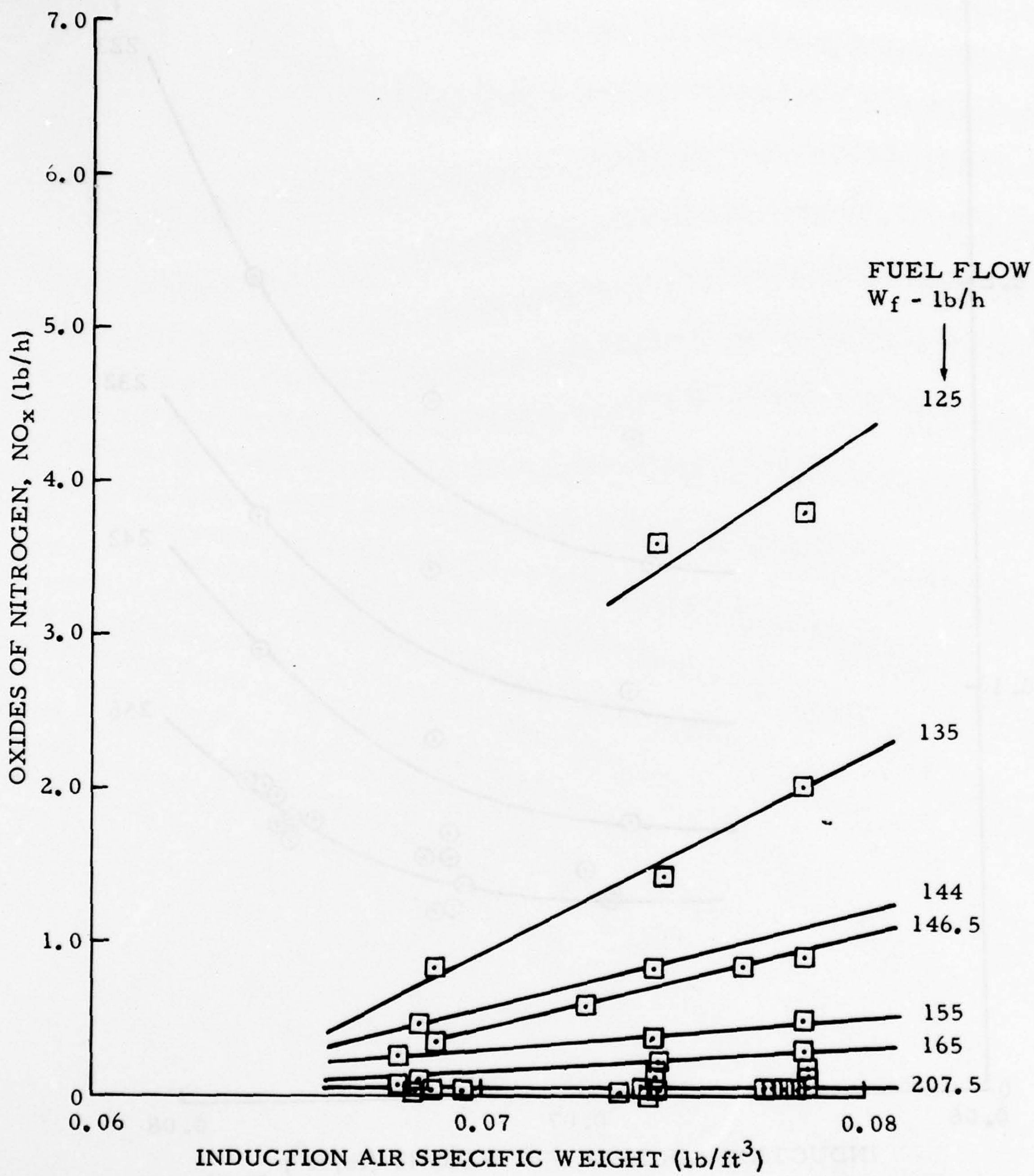


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FIGURE C-14. OXIDES OF NITROGEN (NO_x) AS A FUNCTION OF INDUCTION AIR SPECIFIC WEIGHT FOR SEVERAL CLIMB MODE CONSTANT FUEL FLOW SCHEDULES--AVCO LYCOMING TIO-540-J2BD ENGINE

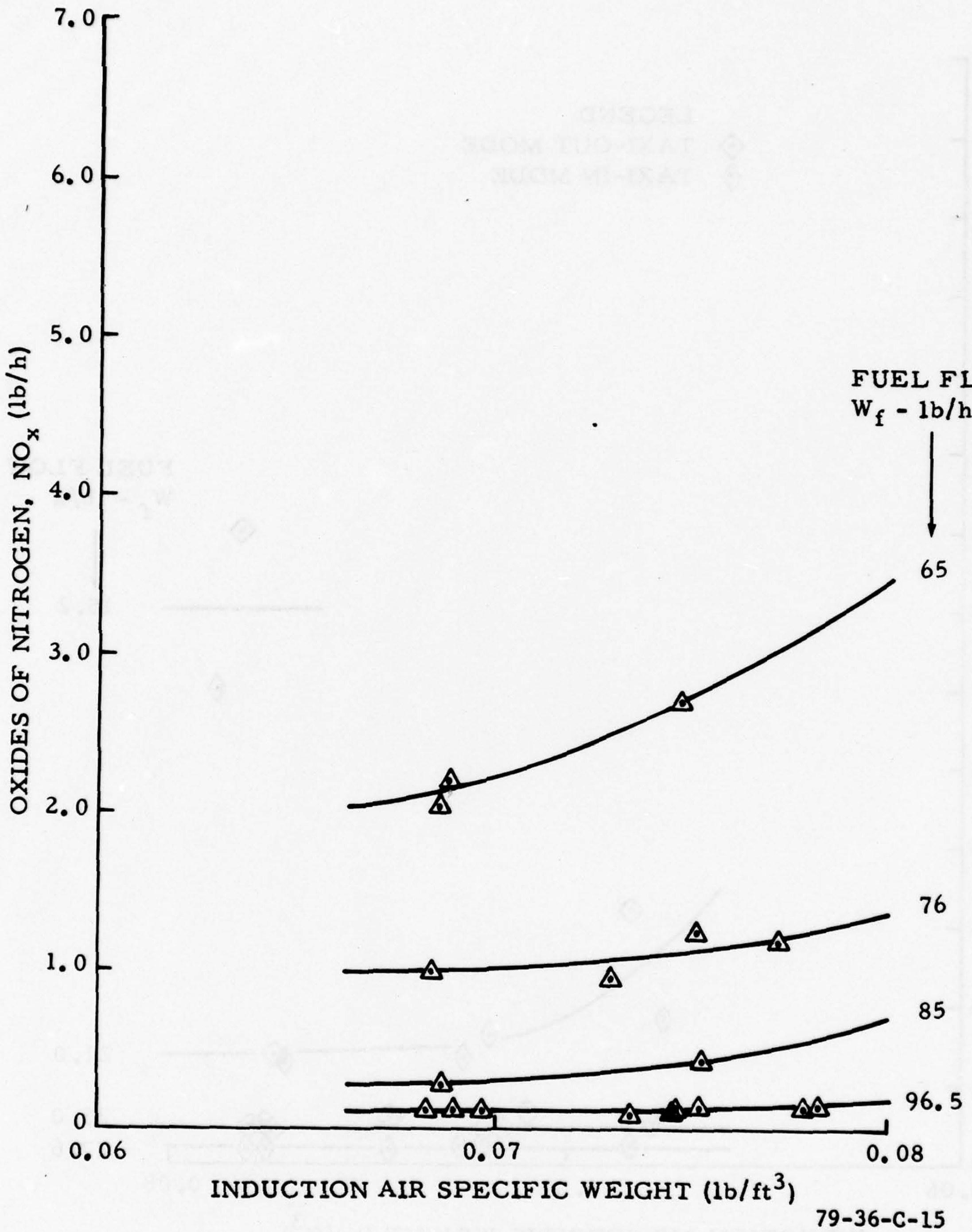

FIGURE C-15. OXIDES OF NITROGEN (NO_x) AS A FUNCTION OF INDUCTION AIR SPECIFIC WEIGHT FOR SEVERAL APPROACH MODE CONSTANT FUEL FLOW SCHEDULES--AVCO LYCOMING TIO-540-J2BD ENGINE

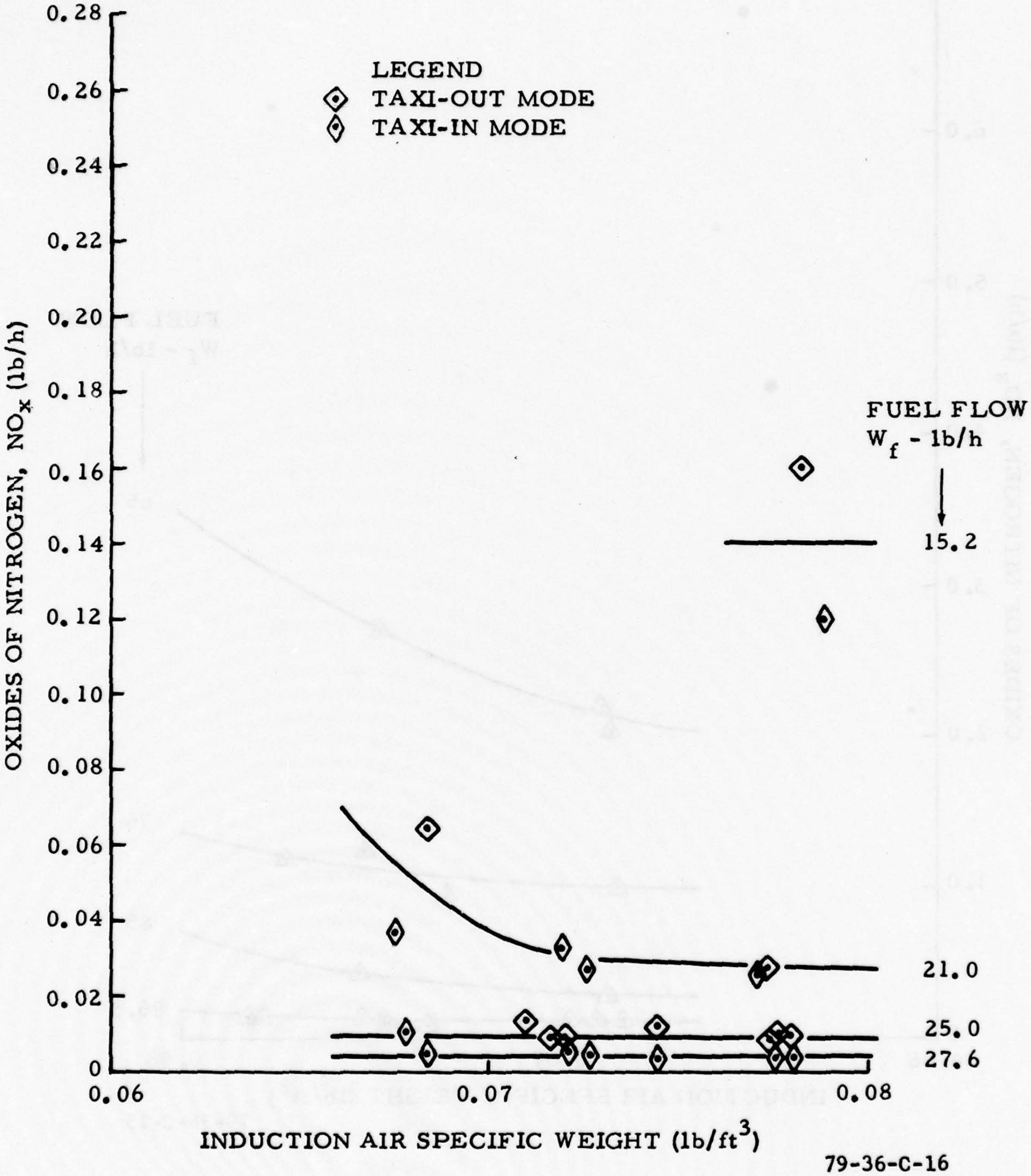

FIGURE C-16. OXIDES OF NITROGEN AS A FUNCTION OF INDUCTION AIR SPECIFIC WEIGHT FOR SEVERAL TAXI MODE FUEL FLOW SCHEDULES--AVCO LYCOMING TIO-540-J2BD ENGINE

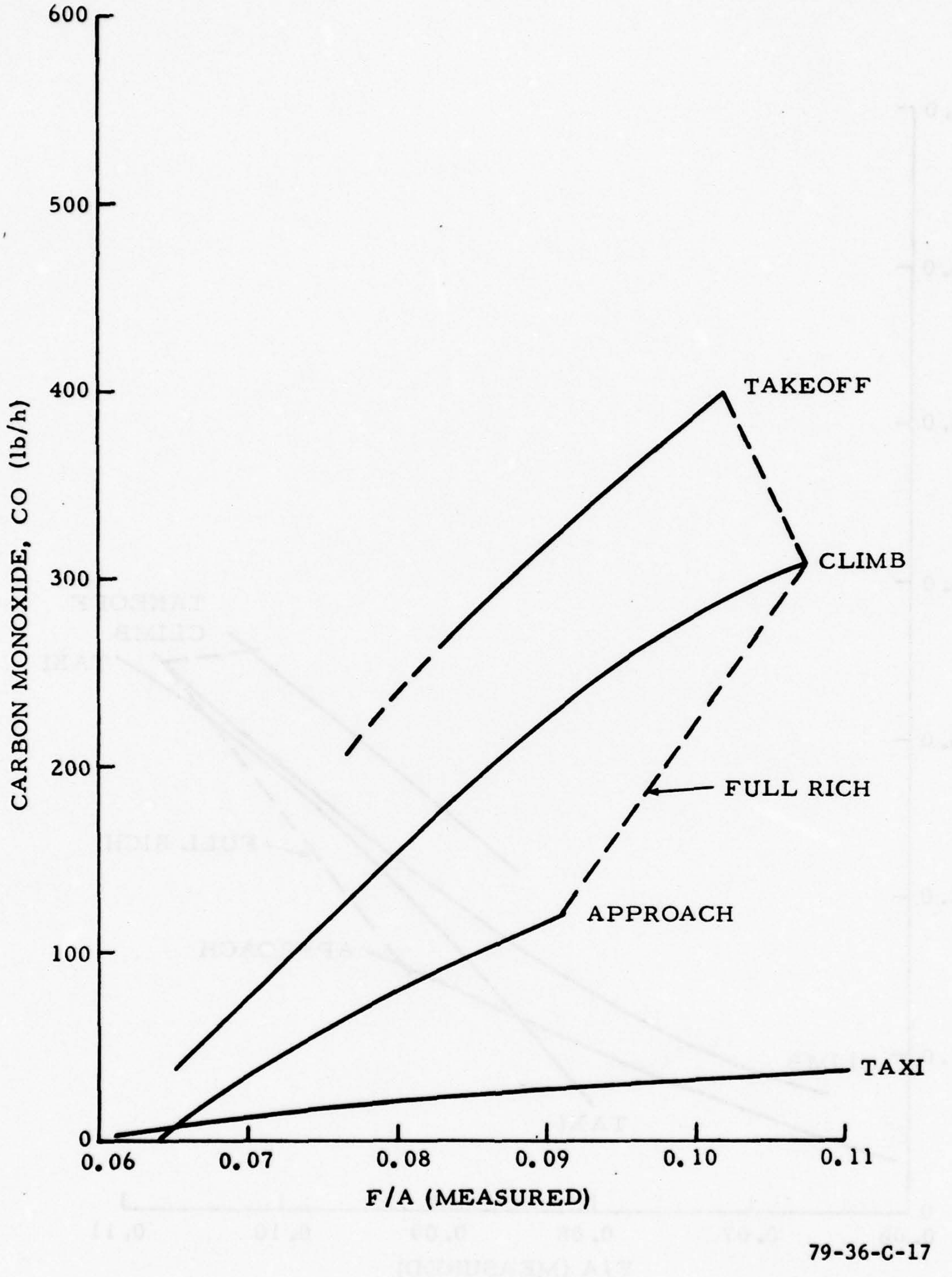

FIGURE C-17. SEA LEVEL STANDARD-DAY EMISSION CHARACTERISTICS FOR AN AVCO LYCOMING TIO-540-J2BD ENGINE--CARBON MONOXIDE

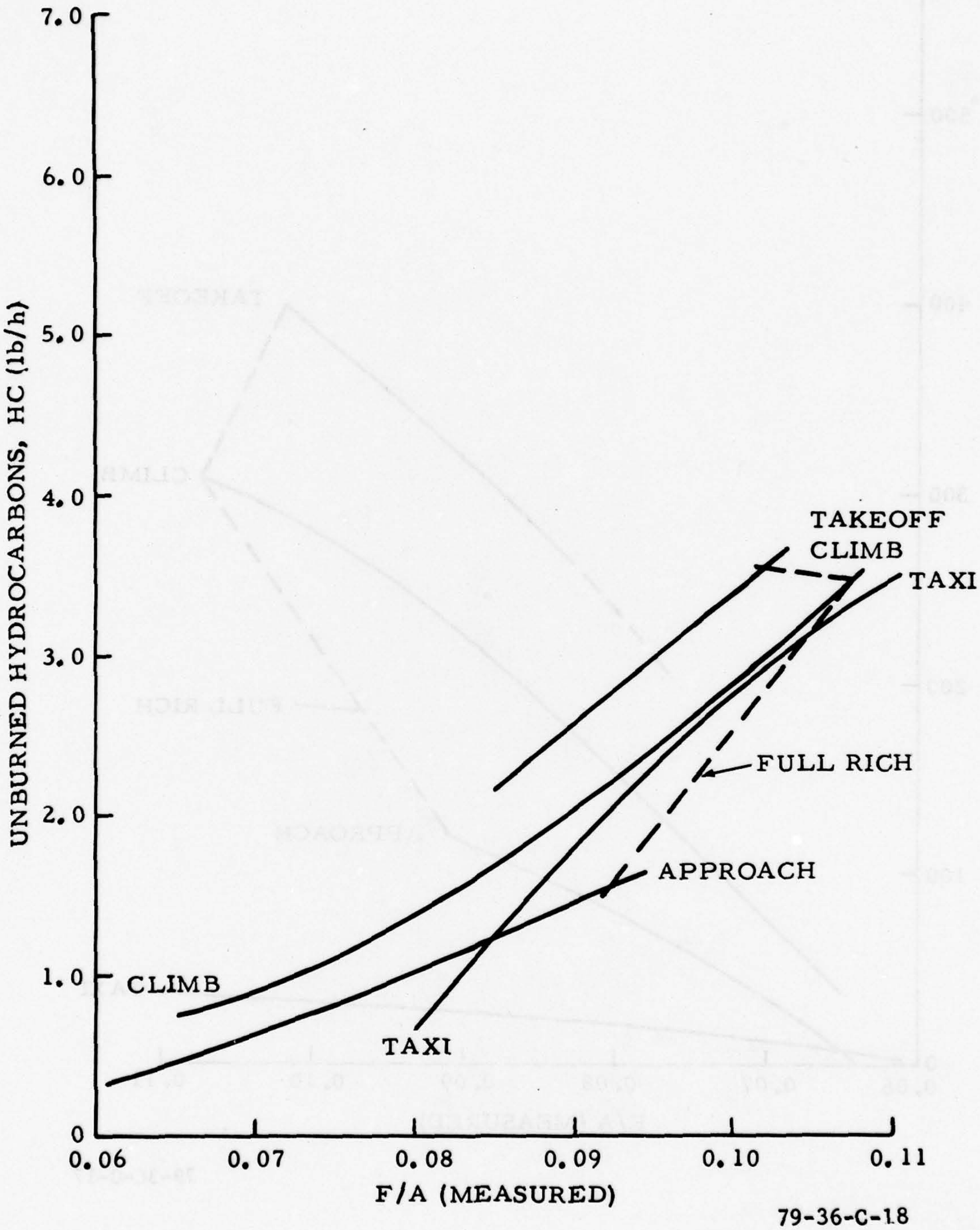

FIGURE C-18. SEA LEVEL STANDARD-DAY EMISSIONS CHARACTERISTICS FOR AN AVCO LYCOMING TIO-540-J2BD ENGINE--UNBURNED HYDROCARBONS

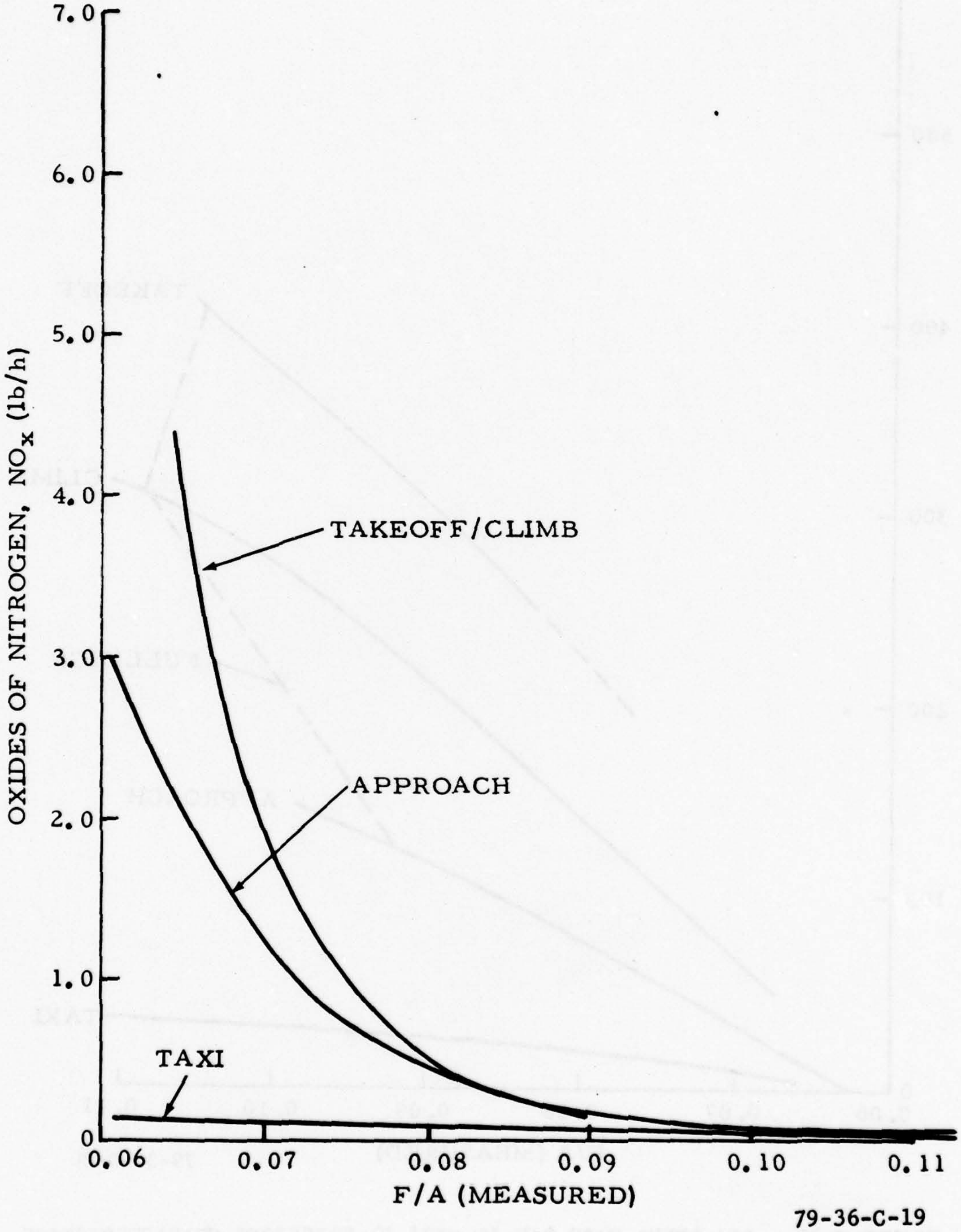

FIGURE C-19. SEA LEVEL STANDARD-DAY EMISSIONS CHARACTERISTICS FOR AN AVCO LYCOMING TIO-540-J2BD ENGINE--OXIDES OF NITROGEN

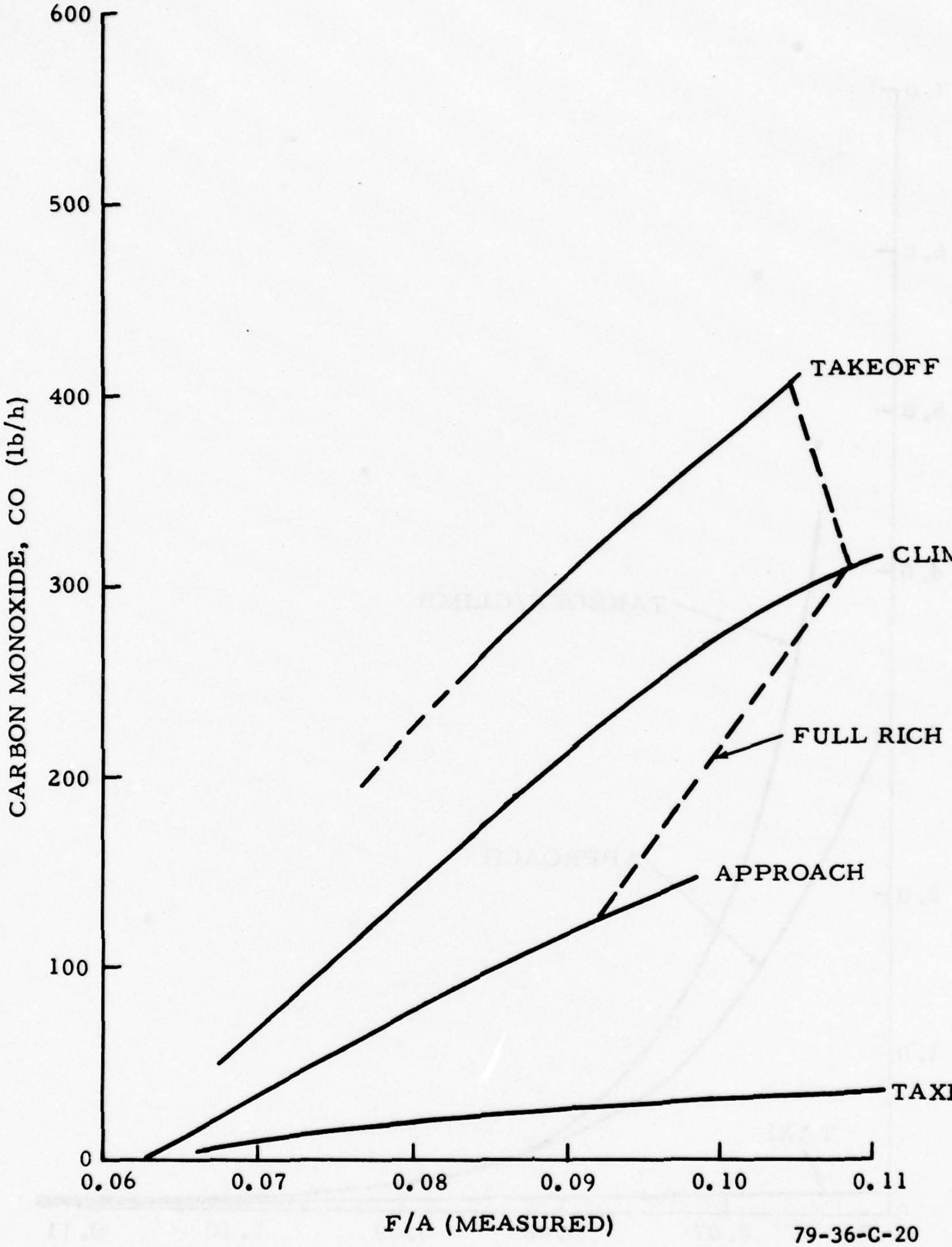

FIGURE C-20. SEA LEVEL WARM DAY (T_i=80° F) EMISSIONS CHARACTERISTICS FOR AN AVCO LYCOMING TIO-540-J2BD ENGINE--CARBON MONOXIDE

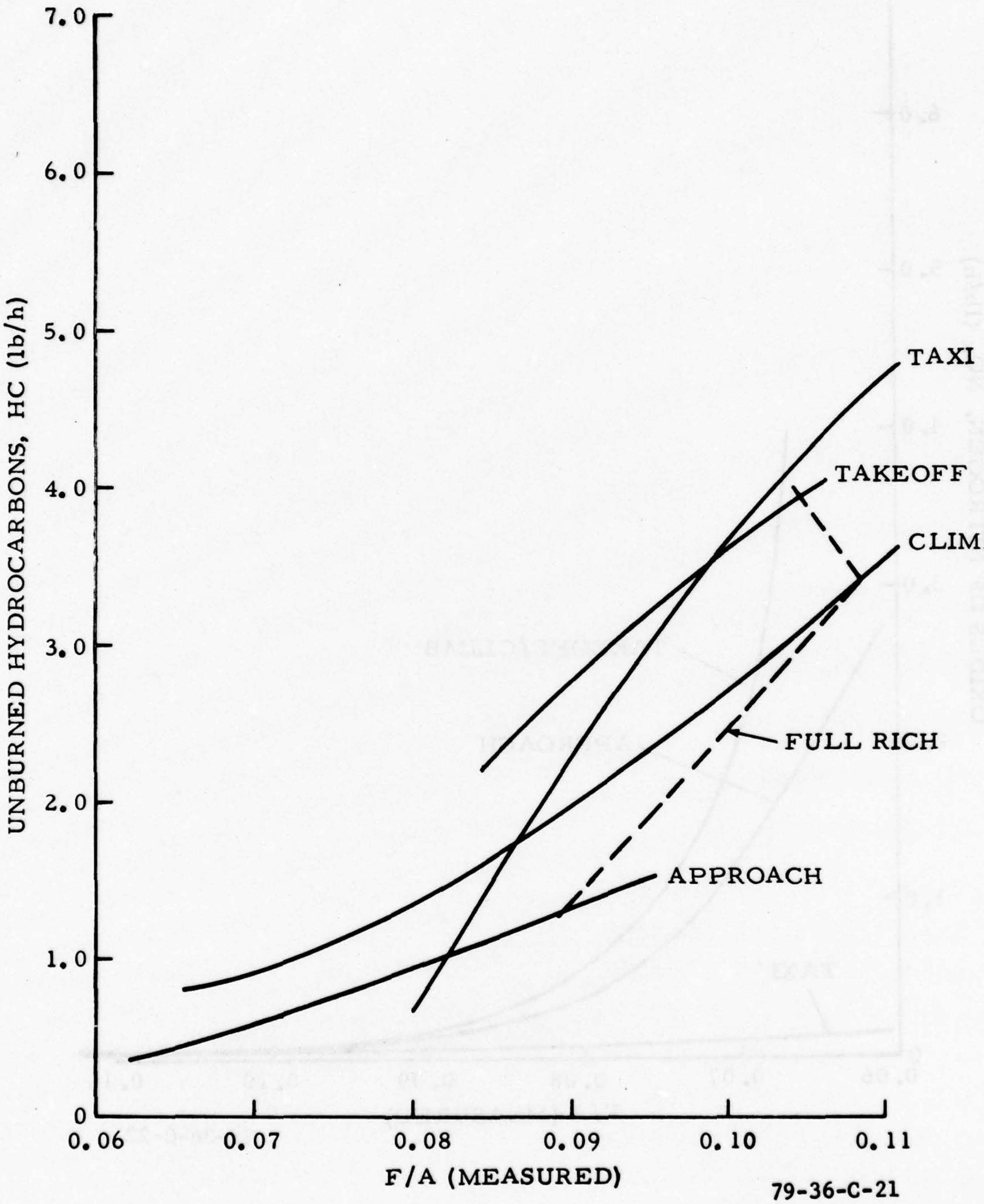

FIGURE C-21. SEA LEVEL WARM DAY (T_i=80° F) EMISSIONS CHARACTERISTICS FOR AN AVCO LYCOMING TIO-540-J2BD ENGINE--UNBURNED HYDROCARBONS

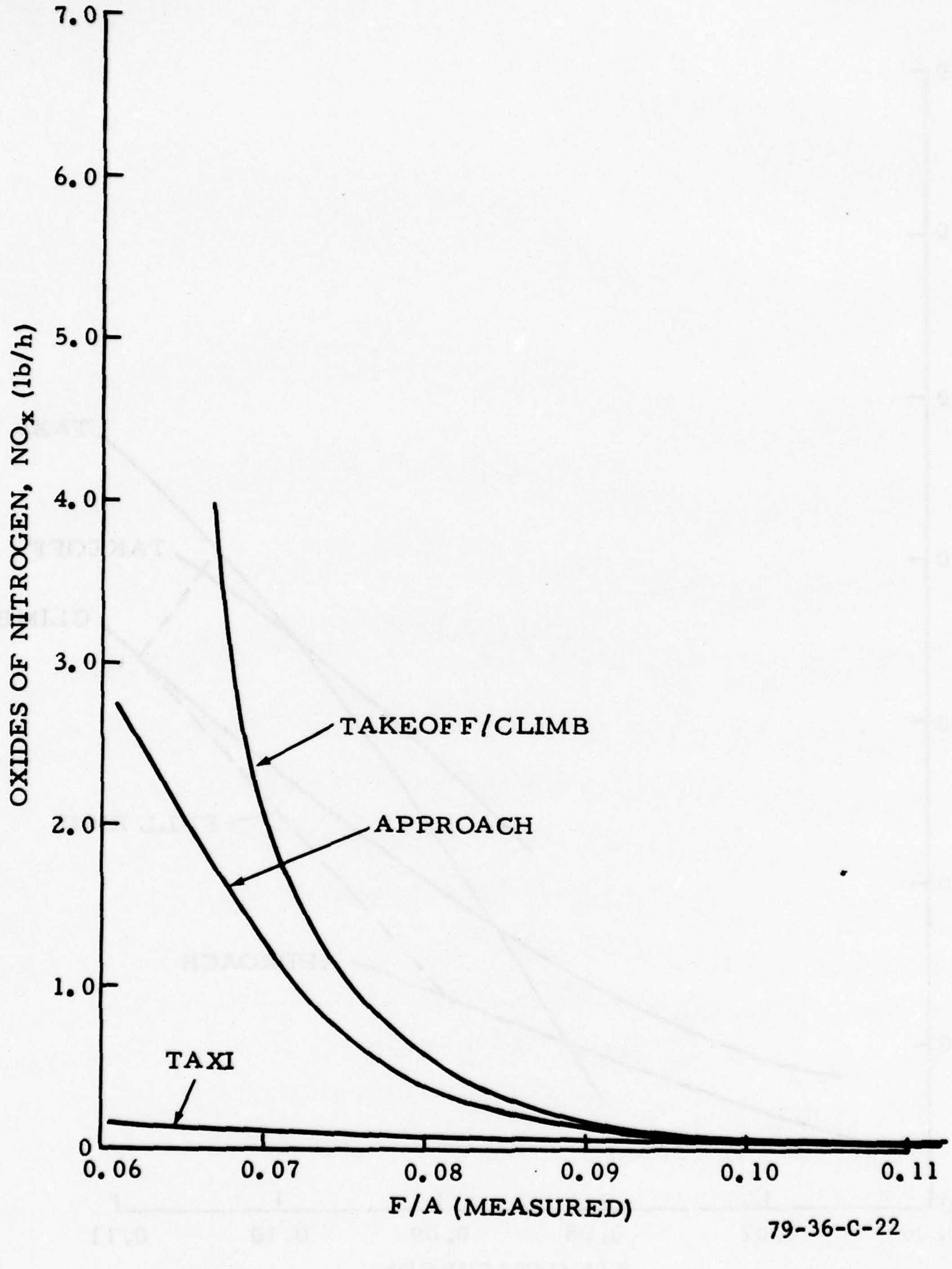

FIGURE C-22. SEA LEVEL WARM DAY (T_1=80° F) EMISSIONS CHARACTERISTICS FOR AN AVCO LYCOMING TIO-540-J2BD ENGINE--OXIDES OF NITROGEN

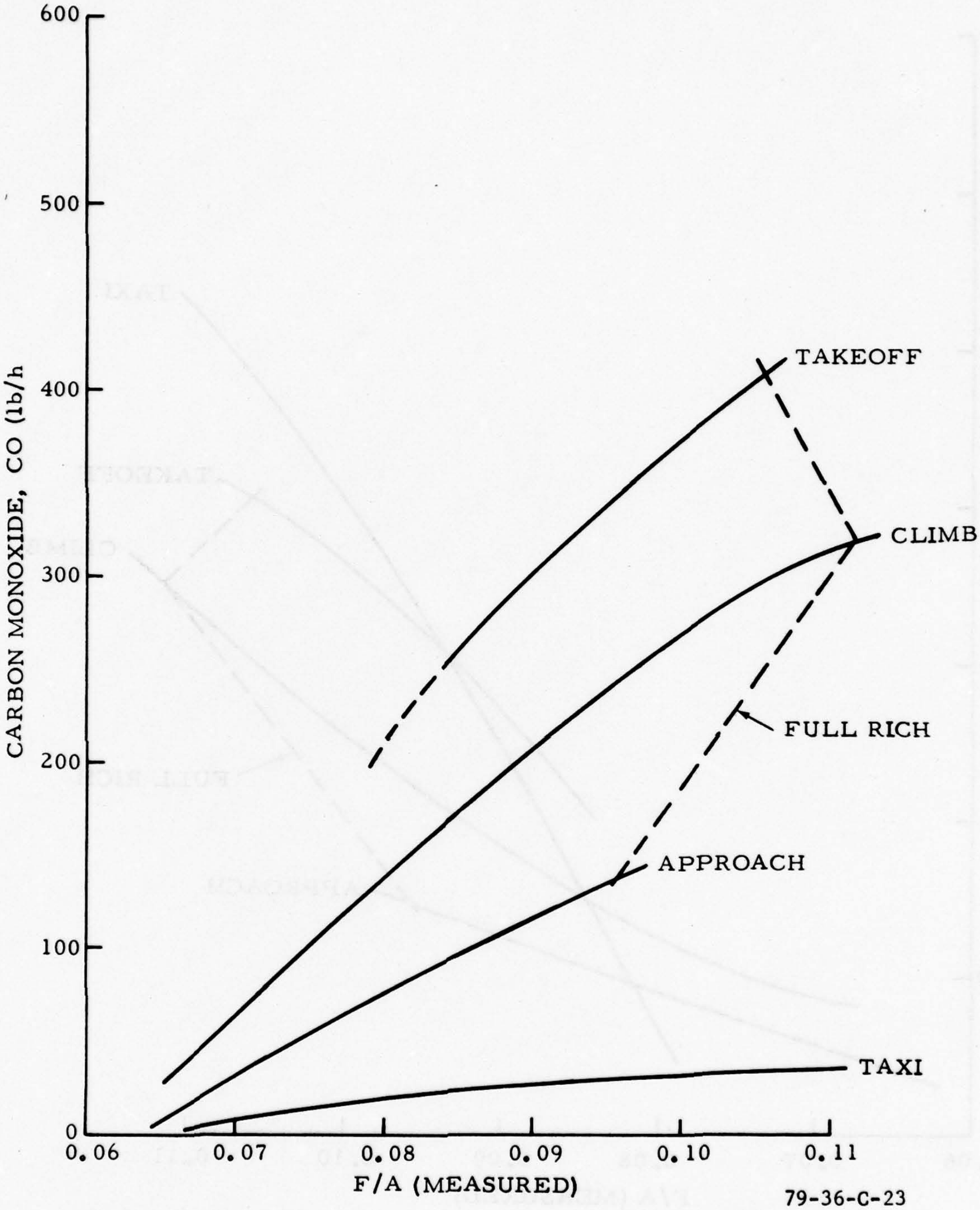

FIGURE C-23. SEA LEVEL HOT-DAY (T_1=100° F) EMISSIONS CHARACTERISTICS FOR AN AVCO LYCOMING TIO-540-J2BD ENGINE--CARBON MONOXIDE

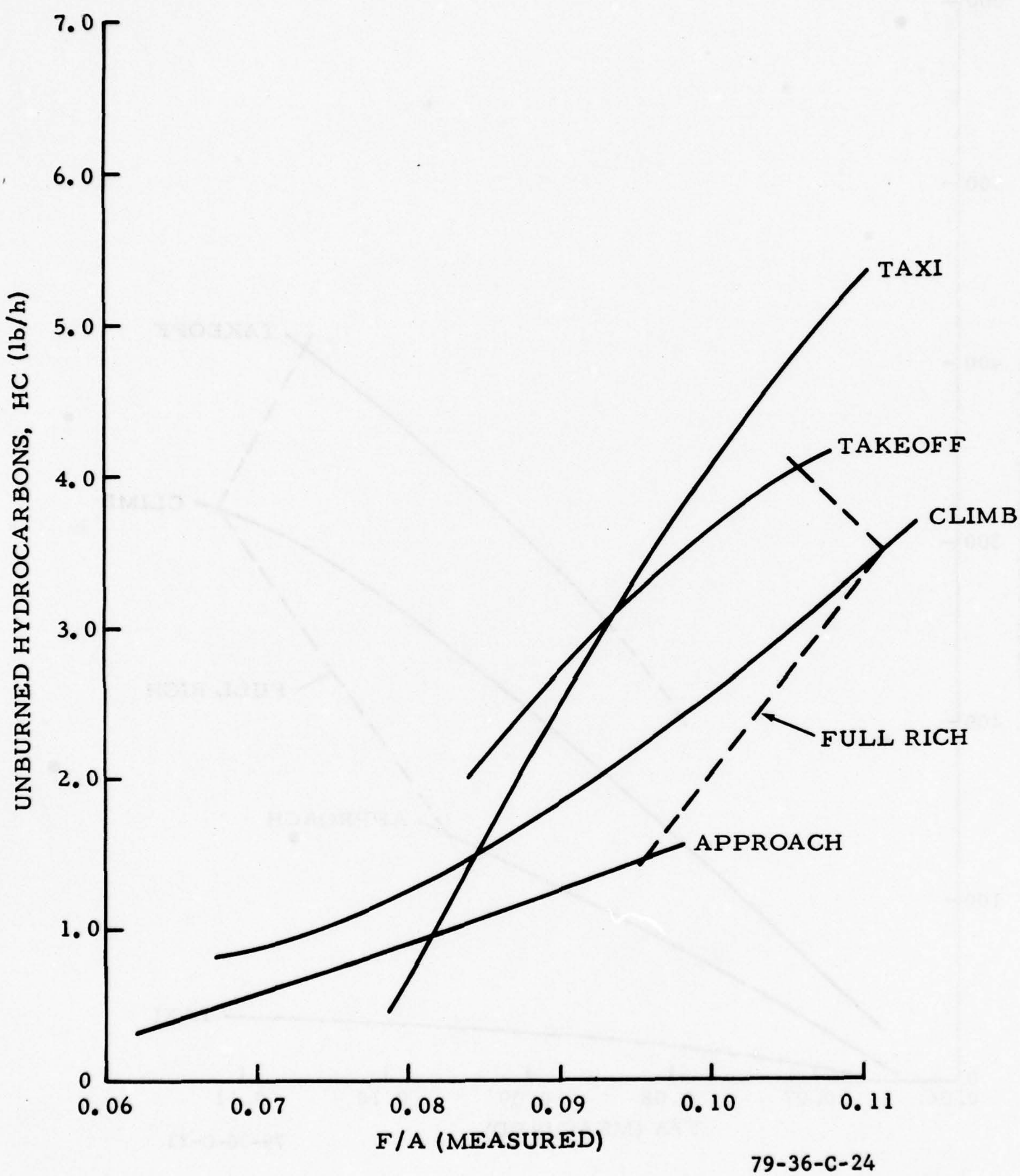

FIGURE C-24. SEA LEVEL HOT-DAY (T_1=100° F) EMISSIONS CHARACTERISTICS FOR AN AVCO LYCOMING TIO-540-J2BD ENGINE--UNBURNED HYDROCARBONS

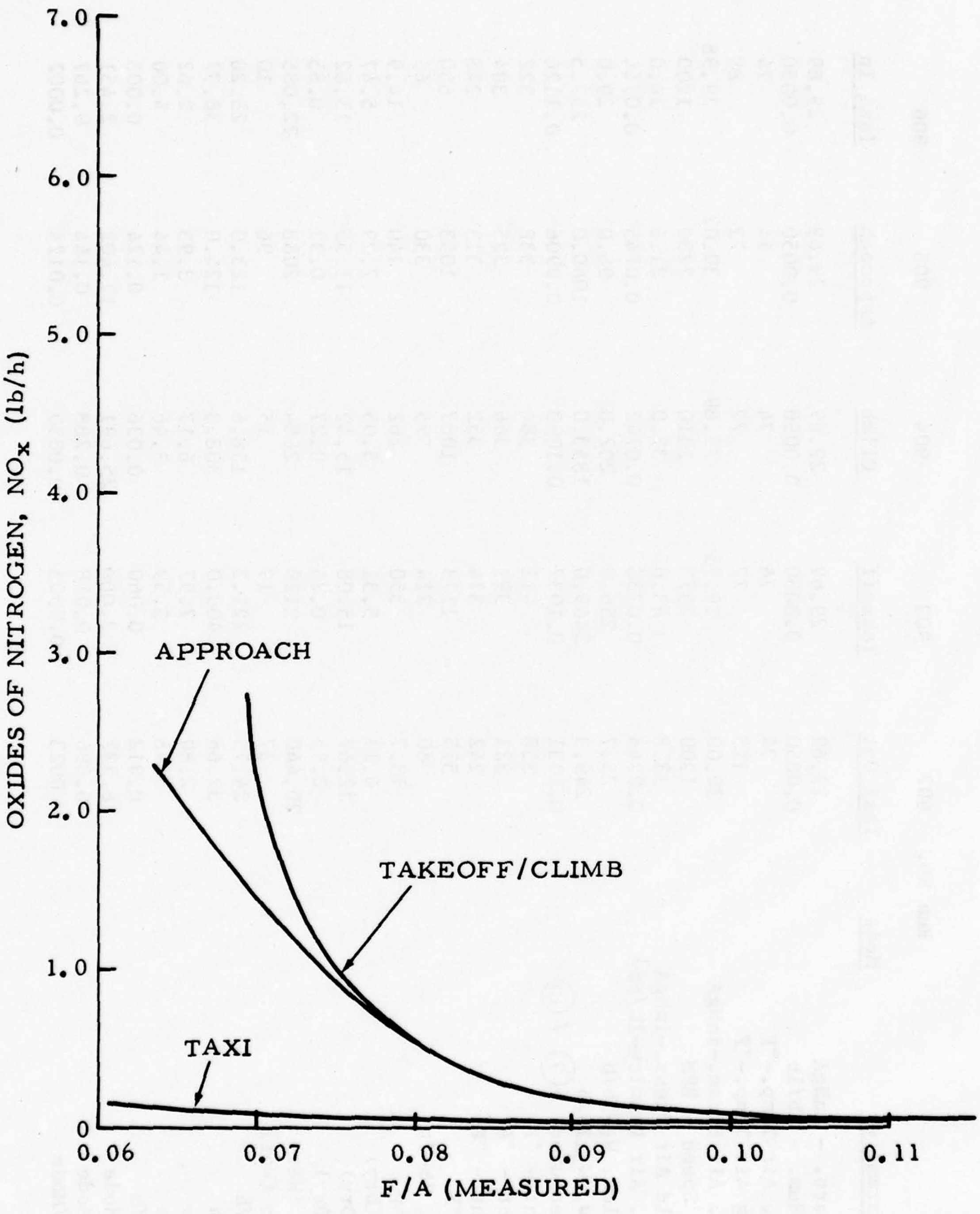

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FIGURE C-25. SEA LEVEL HOT DAY (T_i=100° F) EMISSIONS CHARACTERISTICS FOR AN AVCO LYCOMING TIO-540-J2BD ENGINE--OXIDES OF NITROGEN

TABLE C-1. AVCO LYCOMING TIO-540-J2BD ENGINE (S/N 890-X) NAFEC TEST DATA--BASELINE #1--(NO IDLE, FIVE MODE) SPARK SETTING 20°BTC

	Run No.	902	903	904	905	906
Parameter	Mode	Taxi Out	Takeoff	Climb	Approach	Taxi In
1. Act. Baro. - inHgA		29.69	29.69	29.69	29.69	29.69
2. Spec. Hum. - lb/lb		0.0050	0.0050	0.0050	0.0050	0.0050
3. Induct. Air Temp.-°F		74	74	74	74	74
4. Cooling Air Temp.-°F		115	72	72	73	89
5. Induct. Air Press.-inHgA		30.00	29.75	29.89	30.02	29.98
6. Engine Speed - RPM		1200	2575	2310	2230	1200
7. Manifold Air Press.-inHgA		13.8	43.6	37.0	21.6	14.0
8. Induct. Air Density-lb/ft^3		0.0744	0.0738	0.0742	0.0745	0.0744
9. Fuel Flow, W_f-lb/h		25.7	256.0	202.0	96.0	29.0
10. Airflow, W_a-lb/h		249.3	2469.0	1853.0	1060.0	257.5
11. F/A (Measured) = 9 / 10		0.1031	0.1037	0.1090	0.0906	0.1126
12. Max. Cht - °F		358	411	384	338	322
13. Avg. Cht - °F		321	391	366	325	304
14. Min. Cht - °F		242	374	352	313	248
15. EGT - °F		575	1173	1087	1053	650
16. Torque, lb-ft		60	714	595	330	65
17. OBS. Bhp		13.7	350	262	140	14.9
18. % CO_2 (Dry)		6.11	5.31	5.05	7.29	5.47
19. % CO (Dry)		12.67	15.08	15.42	11.55	13.62
20. % O_2 (Dry)		0.95	0.25	0.27	0.32	0.85
21. HC-ppm (Wet)		20,460	2129	2684	2088	22,085
22. NO_x-ppm (Wet)		37	19	15	96	10
23. CO_2-lb/h		24.75	221.3	158.6	123.0	23.20
24. CO-lb/h		32.66	400.0	308.3	124.0	36.77
25. O_2-lb/h		2.80	7.57	6.17	3.93	2.62
26. HC-lb/h		3.48	3.59	3.46	1.44	4.00
27. NO_x-lb/h		0.012	0.060	0.036	0.124	0.003
28. CO-lb/Mode		6.532	2.000	25.691	12.402	2.451
29. HC-lb/Mode		0.696	0.018	0.288	0.144	0.267
30. NO_x-lb/Mode		0.0023	0.0003	0.0030	0.0124	0.0002

TABLE C-2. AVCO LYCOMING TIO-540-J2BD ENGINE (S/N890-X) NAFEC TEST DATA--BASELINE #2--(NO IDLE, FIVE MODE) SPARK SETTING 20° BTC

	Parameter	Run No.	2	3	4	5	6
		Mode	Taxi Out	Takeoff	Climb	Approach	Taxi In
1.	Act. Baro. - inHgA		30.20	30.20	30.20	30.20	30.20
2.	Spec. Hum. - lb/lb		0.0030	0.0030	0.0030	0.0030	0.0030
3.	Induct. Air Temp.-°F		63	61	61	60	61
4.	Cooling Air Temp.-°F		93	57	57	57	68
5.	Induct. Air Press.-inHgA		30.53	30.30	30.42	30.51	30.52
6.	Engine Speed - RPM		1200	2575	2310	2240	1210
7.	Manifold Air Press.-inHgA		13.1	42.6	37.0	21.6	13.2
8.	Induct. Air Density-lb/ft^3		0.0774	0.0771	0.0774	0.0778	0.0776
9.	Fuel Flow, W_f-lb/h		24.6	256.0	212.5	98.0	27.0
10.	Airflow, W_a-lb/h		245.0	2494.0	1959.0	1090.0	259.0
11.	F/A (Measured) = 9 / 10		0.1004	0.1026	0.1085	0.0899	0.1042
12.	Max. Cht - °F		372	409	366	328	330
13.	Avg. Cht - °F		335	388	346	313	310
14.	Min. Cht - °F		250	371	332	300	257
15.	EGT - °F		577	1184	1094	1069	647
16.	Torque, lb-ft		70	725	623	354	75
17.	Obs. Bhp		16.0	355	274	151	17
18.	% CO_2 (Dry)		6.15	5.41	4.96	7.65	5.80
19.	% CO (Dry)		12.96	14.85	15.44	10.90	13.59
20.	% O_2 (Dry)		0.59	0.22	0.23	0.28	0.54
21.	HC-ppm (Wet)		13,627	2080	2964	2038	13,508
22.	NO_x-ppm (Wet)		26	22	13	112	13
23.	CO_2-lb/h		24.62	227.4	164.8	131.7	24.79
24.	CO-lb/h		33.02	397.2	326.5	119.4	36.97
25.	O_2-lb/h		1.72	6.72	5.56	3.50	1.68
26.	HC-lb/h		2.25	3.53	4.03	1.44	2.47
27.	NO_x-lb/h		0.008	0.070	0.033	0.149	0.004
28.	CO-lb/Mode		6.603	1.986	27.207	11.943	2.465
29.	HC-lb/Mode		0.450	0.018	0.336	0.144	0.165
30.	NO_x-lb/Mode		0.0016	0.0003	0.0028	0.0149	0.0003

TABLE C-3. AVCO LYCOMING TIO-540-J2BD ENGINE (S/N890-X) NAFEC TEST DATA--BASELINE #3--(NO IDLE, FIVE MODE) SPARK SETTING 20° BTC

	Parameter	Run No. / Mode	31 Taxi Out	32 Takeoff	33 Climb	34 Approach	36 Taxi In
1.	Act. Baro. - inHgA		29.95	29.95	29.95	29.95	29.95
2.	Spec. Hum. - lb/lb		0.0055	0.0055	0.0055	0.0055	0.0055
3.	Induct. Air Temp.-°F		53	50	50	50	49
4.	Cooling Air Temp.-°F		85	47	47	47	88
5.	Induct. Air Press.-inHgA		30.27	30.06	30.18	30.30	30.28
6.	Engine Speed - RPM		1200	2575	2320	2240	1200
7.	Manifold Air Press.-inHgA		14.3	43.0	37.0	21.9	14.4
8.	Induct. Air Density-lb/ft^3		0.0782	0.0781	0.0784	0.0787	0.0788
9.	Fuel Flow, W_f-lb/h		15.2	258.0	210.0	101.0	15.2
10.	Airflow, W_a-lb/h		264.7	2530.0	1963.0	1104.0	254.9
11.	F/A (Measured) -9 / 10		0.0574	0.1020	0.1070	0.0915	0.0596
12.	Max. Cht - °F		412	410	357	316	368
13.	Avg. Cht - °F		355	389	335	302	321
14.	Min. Cht - °F		257	368	320	288	239
15.	EGT - °F		645	1193	1095	1065	672
16.	Torque, lb-ft		65	734	620	353	65
17.	Obs. Bhp		15	360	274	151	15
18.	% CO_2 (Dry)		11.58	5.59	5.14	7.66	11.91
19.	% CO (Dry)		0.84	14.67	15.51	11.05	0.35
20.	% O_2 (Dry)		3.49	0.26	0.28	0.30	3.48
21.	HC-ppm (Wet)		4931	1924	2781	1960	2046
22.	NO_x-ppm (Wet)		543	24	12	103	414
23.	CO_2-lb/h		43.63	237.5	172.4	133.7	43.00
24.	CO-lb/h		2.01	396.8	331.1	122.8	0.80
25.	O_2-lb/h		9.56	8.03	6.83	3.81	9.14
26.	HC-lb/h		0.77	3.30	3.77	1.41	0.31
27.	NO_x-lb/h		0.16	0.08	0.03	0.14	0.12
28.	CO -lb/Mode		0.403	1.984	27.592	12.278	0.054
29.	HC-lb/Mode		0.154	0.017	0.314	0.141	0.021
30.	NO_x-lb/Mode		0.0320	0.0004	0.0025	0.0139	0.0078

TABLE C-4. AVCO LYCOMING TIO-540-J2BD ENGINE (S/N890-X) NAFEC TEST DATA—BASELINE #4—(NO IDLE, FIVE MODE) SPARK SETTING 20° BTC

		Run No.	908	909	910	911	912
	Parameter	Mode	Taxi Out	Takeoff	Climb	Approach	Taxi In
1.	Act. Baro. - inHgA		29.94	29.94	29.94	29.94	29.94
2.	Spec. Hum. - lb/lb		0.0030	0.0030	0.0030	0.0030	0.0030
3.	Induct. Air Temp.-°F		57	54	54	54	54
4.	Cooling Air Temp.-°F		93	51	51	51	83
5.	Induct. Air Press.-inHgA		30.27	30.04	30.16	30.28	30.27
6.	Engine Speed - RPM		1200	2575	2320	2240	1200
7.	Manifold Air Press.-inHgA		13.4	42.9	37.0	21.7	13.2
8.	Induct. Air Density-lb/ft^3		0.0776	0.0775	0.0778	0.0781	0.0780
9.	Fuel Flow, W_f-lb/h		24.2	255.0	210.0	99.5	26.9
10.	Airflow, W_a-lb/h		243.9	2500.0	1938.0	1085.0	253.2
11.	F/A (Measured) = 9 / 10		0.0992	0.1020	0.1084	0.0917	0.1062
12.	Max. Cht - °F		388	421	364	324	325
13.	Avg. Cht - °F		352	401	345	310	306
14.	Min. Cht - °F		258	380	330	298	239
15.	EGT - °F		595	1179	1081	1066	638
16.	Torque, lb-ft		70	735	623	352	75
17.	Obs. Bhp		16	360	275	150	17
18.	% CO_2 (Dry)		6.46	5.52	5.03	7.67	5.84
19.	% CO (Dry)		12.91	15.01	15.83	11.10	13.64
20.	% O_2 (Dry)		0.55	0.26	0.28	0.32	0.64
21.	HC-ppm (Wet)		10.918	1932	2605	1881	13,754
22.	NO_x-ppm (Wet)		32	24	13	114	13
23.	CO_2-lb/h		25.43	233.9	167.7	132.1	24.47
24.	CO-lb/h		32.35	404.8	335.9	121.6	36.37
25.	O_2-lb/h		1.57	8.01	6.79	4.01	1.95
26.	HC-lb/h		1.79	3.28	3.51	1.33	2.40
27.	NO_x-lb/h		0.010	0.076	0.033	0.151	0.004
28.	CO-lb/Mode		6.469	2.024	27.996	12.165	2.425
29.	HC-lb/Mode		0.358	0.016	0.292	0.133	0.160
30.	NO_x-lb/Mode		0.0020	0.0004	0.0027	0.0151	0.0003

TABLE C-5. AVCO LYCOMING TIO-540-J2BD ENGINE (S/N890-X)NAFEC TEST DATA--BASELINE #5--(NO IDLE, FIVE MODE) SPARK SETTING 20° BTC

	Run No.	913	914	915	916	917
Parameter	Mode	Taxi Out	Takeoff	Climb	Approach	Taxi In
1. Act. Baro. - inHgA		30.43	30.43	30.43	30.43	30.43
2. Spec. Hum. - lb/lb		0.0045	0.0045	0.0045	0.0045	0.0045
3. Induct. Air Temp.-°F		63	63	63	63	63
4. Cooling Air Temp.-°F		106	62	62	63	105
5. Induct. Air Press.-inHgA		30.76	30.54	30.65	30.77	30.76
6. Engine Speed - RPM		1205	2575	2310	2220	1200
7. Manifold Air Press.-inHgA		12.7	42.6	37.1	21.8	13.0
8. Induct. Air Density-lb/ft^3		0.0779	0.0774	0.0777	0.0780	0.0779
9. Fuel Flow, W_f-lb/h		24.2	255.0	213.0	102.0	26.5
10. Airflow, W_a-lb/h		246.1	2478.0	1955.0	1108.0	252.0
11. F/A (Measured) = 9 / 10		0.0983	0.1029	0.1090	0.0921	0.1052
12. Max. Cht - °F		355	423	366	324	343
13. Avg. Cht - °F		324	400	347	311	311
14. Min. Cht - °F		240	381	333	299	240
15. EGT - °F		608	1187	1094	1066	623
16. Torque, lb-ft		70	720	624	362	74
17. Obs. Bhp		16	353	274	153	17
18. % CO_2 (Dry)		6.63	5.58	5.00	7.46	6.07
19. % CO (Dry)		12.88	15.14	16.10	11.71	13.57
20. % O_2 (Dry)		0.56	0.24	0.28	0.28	0.60
21. HC-ppm (Wet)		11,571	1926	2898	1901	14,092
22. NO_x-ppm (Wet)		30	22	10	90	14
23. CO_2-lb/h		26.74	235.1	169.0	132.3	25.32
24. CO-lb/h		33.06	406.0	346.4	132.5	36.02
25. O_2-lb/h		1.64	7.35	6.89	3.62	1.82
26. HC-lb/h		1.91	3.25	3.94	1.38	2.44
27. NO_x-lb/h		0.0093	0.069	0.026	0.122	0.0039
28. CO-lb/Mode		6.612	2.030	28.863	13.245	2.401
29. HC-lb/Mode		0.382	0.016	0.328	0.138	0.162
30. NO_x-lb/Mode		0.0019	0.0003	0.0021	0.0122	0.0003

TABLE C-6. AVCO LYCOMING TIO-540-J2BD ENGINE (S/N890-X) NAFEC TEST DATA--BASELINE #6--(NO IDLE, FIVE MODE) SPARK SETTING 20° BTC

	Run No.	70	71	72	73	74
Parameter	Mode	Taxi Out	Takeoff	Climb	Approach	Taxi In
1. Act. Baro. - inHgA		30.12	30.12	30.12	30.12	30.11
2. Spec. Hum. - lb/lb		0.0060	0.0060	0.0060	0.0060	0.0060
3. Induct. Air Temp.-°F		122	134	134	138	130
4. Cooling Air Temp.-°F		123	133	134	141	115
5. Induct Air Press.-inHgA		30.01	30.68	30.84	30.98	30.03
6. Engine Speed - RPM		1200	2575	2320	2230	1190
7. Manifold Air Press.-inHgA		15.2	44.0	36.9	21.7	13.8
8. Induct. Air Density-lb/ft^3		0.0683	0.0684	0.0688	0.0687	0.0675
9. Fuel Flow, W_f-lb/h		23.0	225.0	150.0	65.0	23.0
10. Airflow, W_a-lb/h		260.8	2339.0	1751.0	1018.0	228.1
11. F/A (Measured) = 9 / 10		0.0882	0.0962	0.0857	0.0638	0.1008
12. Max. Cht - °F		430	497	491	424	401
13. Avg. Cht - °F		382	475	463	412	369
14. Min. Cht - °F		290	456	444	404	283
15. EGT - °F		636	1231	1232	1226	618
16. Torque, lb-ft		72	704	595	310	70
17. OBS, Bhp		16	345	263	132	16
18. % CO_2 (Dry)		7.57	6.65	8.57	13.15	6.62
19. % CO (Dry)		8.83	13.47	10.05	1.88	9.38
20. % O_2 (Dry)		2.89	0.23	0.24	0.55	2.99
21. HC-ppm (Wet)		24,319	1575	1270	624	39,993
22. NO_x-ppm (Wet)		204	56	168	1944	127
23. CO_2-lb/h		30.69	257.4	234.4	190.3	23.48
24. CO-lb/h		22.78	331.9	174.9	17.3	21.18
25. O_2-lb/h		8.52	6.47	4.77	5.79	7.71
26. HC-lb/h		4.10	2.45	1.42	0.378	6.16
27. NO_x-lb/h		0.064	0.163	0.352	2.201	0.037
28. CO-lb/Mode		4.556	1.659	14.578	1.732	1.412
29. HC-lb/Mode		0.820	0.012	0.119	0.038	0.411
30. NO_x-lb/Mode		0.0128	0.0008	0.0294	0.2201	0.0024

TABLE C-7. AVCO LYCOMING TIO-540-J2BD ENGINE (S/N890-X) NAFEC TEST DATA--BASELINE #7--(NO IDLE, FIVE MODE) SPARK SETTING 20° BTC

	Run No.	37	38	38	40	41
Parameter	Mode	Taxi Out	Takeoff	Climb	Approach	Taxi In
1. Act. Baro - inHgA		30.16	30.16	30.16	30.16	30.15
2. Spec. Hum. -lb/lb		0.0055	0.0055	0.0055	010055	0.0055
3. Induct. Air Temp.-°F		102	130	135	135	127
4. Cooling Air Temp.-°F		99	135	138	138	117
5. Induct. Air Press.-inHgA		30.07	30.71	30.86	30.62	30.05
6. Engine Speed - RPM		1200	2575	2310	2230	1200
7. Manifold Air Press.-inHgA		13.3	44.2	37.0	21.7	14.0
8. Induct. Air Density-lb/ft^3		0.0709	0.0690	0.0687	0.0682	0.0678
9. Fuel Flow, W_f-lb/h		24.8	256.0	199.0	93.5	27.7
10. Airflow, W_a-lb/h		236.8	2397.0	1801.0	1014.0	255.8
11. F/A (Measured)=9 / 10		0.1047	0.1068	0.1105	0.0922	0.1083
12. Max. Cht - °F		375	457	404	372	366
13. Avg. Cht - °F		351	434	384	360	339
14. Min. Cht - °F		274	415	371	344	254
15. EGT - °F		635	1163	1079	1052	653
16. Torque, lb-ft		70	685	555	318	80
17. OBS. Bhp		16	336	244	135	18
18. % CO_2 (Dry)		6.19	5.05	4.72	7.19	5.79
19. % CO (Dry)		12.48	16.01	16.66	12.36	12.80
20. % O_2 (Dry)		1.15	0.26	0.31	0.30	1.72
21. HC-ppm (Wet)		24,097	2287	3331	2071	30,171
22. NO_x-ppm (Wet)		42	16	10	92	31
23. CO_2-lb/h		23.80	208.9	145.9	118.3	24.32
24. CO-lb/h		30.54	421.5	327.8	129.4	34.23
25. O_2-lb/h		3.22	7.82	6.97	3.59	5.25
26. HC-lb/h		3.90	3.78	4.19	1.38	5.36
27. NO_x-lb/h		0.013	0.050	0.023	0.114	0.010
28. CO-lb/Mode		6.108	2.107	27.313	12.938	2.282
29. HC-lb/Mode		0.781	0.019	0.349	0.138	0.357
30. NO_x-lb/Mode		0.0025	0.0002	0.0020	0.0114	0.0007

TABLE C-8. AVCO LYCOMING TIO-540-J2BD ENGINE (S/N890-X) NAFEC TEST DATA—BASELINE #8—(NO IDLE, FIVE MODE) SPARK SETTING 20° BTC

	Run No.	55	56	57	58	59
Parameter	Mode	Taxi Out	Takeoff	Climb	Approach	Taxi In
1. Act. Baro. -inHgA		30.20	30.20	30.20	30.20	30.19
2. Spec. Hum. - lb/lb		0.0040	0.0040	0.0040	0.0040	0.0050
3. Induct. Air Temp. -°F		97	124	129	131	124
4. Cooling Air Temp. -°F		93	129	132	136	104
5. Induct. Air Press.-inHgA		30.11	30.73	30.89	31.05	30.09
6. Engine Speed - RPM		1200	2575	2310	2230	1190
7. Manifold Air Press.-inHgA		13.1	43.5	37.0	21.8	13.6
8. Induct. Air Density-lb/ft^3		0.0716	0.0697	0.0695	0.0696	0.0683
9. Fuel Flow, W_f-lb/h		25.1	259.0	202.0	95.5	27.3
10. Airflow, W_a-lb/h		244.3	2439.0	1866.0	1002.0	251.3
11. F/A (Measured) = 9 / 10		0.1027	0.1062	0.1083	0.0953	0.1086
12. Max. Cht - °F		353	453	403	370	370
13. Avg. Cht - °F		334	430	385	357	346
14. Min. Cht - °F		262	407	367	343	281
15. EGT - °F		622	1159	1071	1048	660
16. Torque, lb-ft		72	708	585	332	75
17. OBS. Bhp		16	347	257	141	17
18. % CO_2 (Dry)		6.32	5.09	4.76	7.15	5.67
19. % CO (Dry)		12.47	15.32	15.82	11.69	13.34
20. % O_2 (Dry)		0.68	0.23	0.27	0.31	0.83
21. HC-ppm (Wet)		16,290	2138	2918	1898	20,011
22. NO_x-ppm (Wet)		30	18	12	99	15
23. CO_2-lb/h		24.98	211.0	152.0	114.5	23.13
24. CO -lb/h		31.38	404.1	321.6	119.2	34.63
25. O_2 -lb/h		1.96	6.93	6.27	3.61	2.46
26. HC -lb/h		2.71	3.59	3.78	1.26	3.49
27. NO_x-lb/h		0.009	0.056	0.029	0.123	0.005
28. CO-lb/Mode		6.276	2.021	26.800	11.916	2.309
29. HC-lb/Mode		0.542	0.018	0.315	0.126	0.233
30. NO_x-lb/Mode		0.0019	0.0003	0.0024	0.0123	0.0003

TABLE C-9. AVCO LYCOMING TIO-540-J2BD ENGINE (S/N890-X) NAFEC TEST DATA--BASELINE #9--(NO IDLE, FIVE MODE) SPARK SETTING 20° BTC

	Run No.	75	76	77	78	79
Parameter	Mode	Taxi Out	Takeoff	Climb	Approach	Taxi In
1. Act. Baro. - inHgA		30.38	30.38	30.38	30.38	30.38
2. Spec. Hum. - lb/lb		0.0100	0.0100	0.0100	0.0100	0.0100
3. Induct. Air Temp.-°F		98	99	94	96	93
4. Cooling Air Temp.-°F		85	104	93	97	83
5. Induct. Air Press.-inHgA		30.20	30.46	30.63	30.78	30.19
6. Engine Speed - RPM		1200	2575	2310	2230	1200
7. Manifold Air Press.-inHgA		13.2	44.0	37.0	21.8	13.3
8. Induct. Air Density-lb/ft^3		0.0717	0.0722	0.0733	0.0734	0.0724
9. Fuel Flow, W_f-lb/h		25.5	255.0	208.0	97.0	27.1
10. Airflow, W_a-lb/h		244.1	2444.0	1875.0	1106.0	254.4
11. F/A (Measured) = 9 / 10		0.1045	0.1043	0.1109	0.0877	0.1065
12. Max. Cht - °F		341	432	365	342	352
13. Avg. Cht - °F		322	408	346	327	335
14. Min. Cht - °F		255	390	335	315	275
15. EGT - °F		600	1172	1081	1057	633
16. Torque, lb-ft		76	691	580	339	73
17. OBS. Bhp		17	339	255	144	17
18. % CO_2 (Dry)		6.51	5.27	4.79	7.48	5.90
19. % CO (Dry)		12.26	15.23	16.00	11.31	13.06
20. % O_2 (Dry)		0.69	0.25	0.27	0.29	0.90
21. HC-ppm (Wet)		16,544	2358	3817	2041	22,158
22. NO_x-ppm (Wet)		25	15	7	95	14
23. CO_2-lb/h		25.58	218.7	154.3	131.3	24.49
24. CO-lb/H		30.66	402.2	327.9	179.8	34.50
25. O_2 - lb/h		1.97	7.54	6.32	2.97	2.72
26. HC - lb/h		2.76	3.94	5.05	1.46	3.89
27. NO_x - lb/h		0.008	0.047	0.017	0.127	0.004
28. CO - lb/Mode		6.132	2.011	27.329	17.979	2.300
29. HC - lb/Mode		0.553	0.020	0.421	0.146	0.259
30. NO_x-lb/Mode		0.0016	0.0002	0.0014	0.0006	0.0003

TABLE C-10. AVCO LYCOMING TIO-540-J2BD ENGINE (S/N890=X) NAFEC TEST DATA--BASELINE #10--(NO IDLE, FIVE MODE) SPARK SETTING 20° BTC

	Run No.	93	94	95	96	97
Parameter	Mode	Taxi Out	Takeoff	Climb	Approach	Taxi In
1. Act. Baro. - inHgA		30.28	30.28	30.28	30.28	30.28
2. Spec. Hum. - lb/lb		0.0125	0.0125	0.0125	0.0125	0.0125
3. Induct. Air Temp. -°F		92	100	98	97	95
4. Cooling Air Temp. - °F		100	100	97	96	92
5. Induct. Air Press. -inHgA		30.20	30.89	31.01	30.85	30.18
6. Engine Speed - RPM		1190	2575	2310	2230	1200
7. Manifold Air Press. -inHgA		13.5	43.2	37.0	21.7	13.7
8. Induct. Air Density-lb/ft^3		0.0725	0.0731	0.0736	0.0734	0.0721
9. Fuel Flow, W_f-lb/h		25.8	255.0	206.0	98.5	28.8
10. Airflow, W_a-lb/h		236.4	2448.0	1851.0	1052.0	262.2
11. F/A (Measured) = 9 / 10		0.1091	0.1042	0.1113	0.0936	0.1098
12. Max. Cht - °F		335	436	385	337	351
13. Avg. Cht - °F		318	411	365	326	331
14. Min. Cht - °F		252	389	353	315	260
15. EGT - °F		622	1162	1083	1045	680
16. Torque, lb-ft		65	685	570	325	70
17. OBS. Bhp		15	336	251	138	16
18. % CO_2 (Dry)		6.07	5.18	4.80	7.03	5.73
19. % CO (Dry)		12.86	15.54	16.08	12.11	13.13
20. % O_2 (Dry)		0.97	0.20	0.24	0.28	1.03
21. HC-ppm (Wet)		23,496	2618	4138	2420	27866
22. NO_x-ppm (Wet)		17	15	8	72	14
23. CO_2-lb/h		23.27	215.1	151.8	118.1	24.38
24. CO -lb/h		31.38	410.8	323.7	129.5	35.56
25. O_2 -lb/h		2.70	6.04	5.52	3.42	3.19
26. HC-lb/h		3.86	4.38	5.37	1.68	5.09
27. NO_x-lb/h		0.005	0.047	0.020	0.093	0.005
28. CO-lb/Mode		6.277	2.054	26.977	12.950	2.370
29. HC-lb/Mode		0.772	0.022	0.447	0.168	0.339
30. NO_x-lb/Mode		0.0010	0.0002	0.0016	0.0093	0.0003

TABLE C-11. AVCO LYCOMING TIO-540-J2BD ENGINE (S/N890-X) NAFEC TEST DATA--BASELINE #11--(NO IDLE, FIVE MODE)

	Parameter	Run No. / Mode	108 Taxi Out	109 Takeoff	110 Climb	111 Approach	112 Taxi In
1.	Act. Baro. - inHgA		29.72	29.72	29.72	29.72	29.72
2.	Spec. Hum. - lb/lb		0.0070	0.0070	0.0070	0.0070	0.0070
3.	Induct. Air Temp. - °F		52	52	52	53	53
4.	Cooling Air Temp. - °F		87	55	55	56	70
5.	Induct. Air Press. -inHgA		30.05	29.81	29.94	30.06	30.04
6.	Engine Speed - RPM		1200	2575	2315	2220	1200
7.	Manifold Air Press. -inHgA		13.4	43.3	37.0	21.7	13.5
8.	Induct. Air Density-lb/ft^3		0.0778	0.0772	0.0775	0.0777	0.0776
9.	Fuel Flow, W_f -lb/h		25.2	260.0	208.0	100.0	27.8
10.	Airflow, W_a -lb/h		244.2	2529.0	1934.0	1059.0	257.3
11.	F/A (Measured) = 9/10		0.1032	0.1028	0.1075	0.0944	0.1080
12.	Max. Cht - °F		372	415	358	315	318
13.	Avg. Cht - °F		337	390	339	303	301
14.	Min. Cht - °F		247	372	323	294	236
15.	EGT - °F		610	1177	1087	1039	664
16.	Torque, lb-ft		65	715	610	340	70
17.	OBS. Bhp		15	351	269	144	16
18.	% CO_2 (Dry)		6.18	5.49	5.11	7.43	5.85
19.	% CO (Dry)		13.51	15.42	15.92	11.79	13.80
20.	% O_2 (Dry)		0.50	0.19	0.20	0.27	0.58
21.	HC -ppm (Wet)		12,651	2094	2918	2111	17,292
22.	NO_x -ppm (Wet)		17	20	12	87	11
23.	CO_2 - lb/h		24.90	236.1	169.8	126.0	24.91
24.	CO - lb/h		34.64	422.1	336.7	127.7	37.41
25.	O_2 - lb/h		1.47	5.94	4.83	3.33	1.80
26.	HC - lb/h		2.10	3.60	3.90	1.48	3.08
27.	NO_x - lb/h		0.005	0.065	0.030	0.114	0.004
28.	CO - lb/Mode		6.928	2.110	28.062	12.721	2.494
29.	HC - lb/Mode		0.421	0.018	0.325	0.148	0.206
30.	NO_x - lb/Mode		0.0011	0.0003	0.0025	0.0114	0.0002

TABLE C-12. AVCO LYCOMING TIO-540-J2BD ENGINE (S/N 890-X) NAFEC TEST DATA--BASELINE 12--(NO IDLE, FIVE-MODE) SPARK SETTING 25° BTC

	Run No.	133	134	135	136	137
Parameter	Mode	Taxi Out	Takeoff	Climb	Approach	Taxi In
1. Act. Baro. - inHgA		29.92	29.92	29.92	29.92	29.92
2. Spec. Hum. - lb/lb		0.0055	0.0055	0.0055	0.0055	0.0055
3. Induct. Air Temp.-°F		59	59	60	60	60
4. Cooling Air Temp.-°F		85	65	64	63	79
5. Induct. Air Press.-inHgA		30.26	30.00	30.14	30.26	30.26
6. Engine Speed - RPM		1200	2575	2320	2220	1210
7. Manifold Air Press.-inHgA		12.3	43.1	37.0	21.7	12.2
8. Induct. Air Density-lb/ft^3		0.0773	0.0766	0.0768	0.0771	0.0771
9. Fuel Flow, W_f-lb/h		20.0	257.0	148.0	78.0	20.0
10. Airflow, W_a-lb/h		221.6	2500.0	1867.0	1055.0	221.3
11. F/A (Measured) = 9 / 10		0.0903	0.1028	0.0793	0.0739	0.0904
12. Max. Cht - °F		366	422	452	361	359
13. Avg. Cht - °F		340	397	429	346	337
14. Min. Cht - °F		253	376	410	331	261
15. EGT - °F		588	1178	1286	1171	647
16. Torque, lb-ft		75	720	660	356	75
17. Obs. Bhp		17	353	292	150	17
18. % CO_2 (Dry)		8.47	5.44	10.06	11.57	8.56
19. % CO (Dry)		9.01	14.45	6.58	4.11	9.13
20. % O_2 (Dry)		0.44	0.22	0.21	0.27	0.46
21. HC-ppm (Wet)		4629	2065	988	1105	3975
22. NO_x-ppm (Wet)		99	22	388	992	98
23. CO_2-lb/h		28.73	226.6	278.4	176.4	29.14
24. CO-lb/h		19.45	383.1	115.9	39.9	19.78
25. O_2-lb/h		1.08	6.67	4.22	2.99	1.14
26. HC-lb/h		0.67	3.51	1.16	0.72	0.573
27. NO_x-lb/h		0.027	0.070	0.85	1.20	0.026
28. CO-lb/Mode		3.891	1.916	9.657	3.988	1.319
29. HC-lb/Mode		0.134	0.018	0.096	0.072	0.038
30. NO_x-lb/Mode		0.0053	0.0003	0.0707	0.120	0.0018

TABLE C-13. AVCO LYCOMING TIO-540-J2BD ENGINE (S/N 890-X) NAFEC TEST DATA--BASELINE 13--(NO IDLE, FIVE-MODE)

	Run No.	138	139	140	141	142
Parameter	Mode	Taxi Out	Takeoff	Climb	Approach	Taxi In
1. Act. Baro. - inHgA		29.92	29.92	29.92	29.92	29.92
2. Spec. Hum. - lb/lb		0.0055	0.0055	0.0055	0.0055	0.0055
3. Induct. Air Temp.-°F		86	93	93	94	90
4. Cooling Air Temp.-°F		102	94	94	95	106
5. Induct. Air Press.-inHgA		29.85	30.54	30.35	30.46	29.85
6. Engine Speed - RPM		1200	2575	2320	2230	1200
7. Manifold Air Press.-inHgA		12.2	43.5	37.0	21.6	12.4
8. Induct. Air Density-lb/ft^3		0.0725	0.0732	0.0727	0.0729	0.0719
9. Fuel Flow, W_f-lb/h		20.0	258.0	147.0	77.5	20.0
10. Airflow, W_a-lb/h		219.4	2469.0	1814.0	1048.0	219.2
11. F/A (Measured) = 9 / 10		0.0912	0.1045	0.0810	0.0740	0.0912
12. Max. Cht - °F		350	434	463	385	372
13. Avg. Cht - °F		323	410	444	372	350
14. Min. Cht - °F		245	390	426	358	271
15. EGT - °F		630	1162	1249	1157	647
16. Torque, lb-ft		75	715	635	340	75
17. Obs. Bhp		17	351	280	144	17
18. % CO_2 (Dry)		8.66	5.24	9.51	11.34	8.71
19. % CO (Dry)		9.17	15.30	8.03	4.98	9.12
20. % O_2 (Dry)		0.45	0.21	0.21	0.27	0.49
21. HC-ppm (Wet)		4635	2201	1120	1171	5053
22. NO_x-ppm (Wet)		101	19	276	804	122
23. CO_2-lb/h		29.26	217.1	260.8	173.6	29.42
24. CO-lb/h		19.72	403.4	140.1	48.5	19.60
25. O_2-lb/h		1.10	6.33	4.19	3.00	1.20
26. HC-lb/h		0.664	3.72	1.28	0.752	0.724
27. NO_x-lb/h		0.027	0.060	0.590	0.966	0.033
28. CO-lb/Mode		3.944	2.017	11.679	4.853	1.307
29. HC-lb/Mode		0.133	0.019	0.107	0.075	0.048
30. NO_x-lb/Mode		0.0054	0.0003	0.0491	0.0966	0.0022

TABLE C-14. AVCO LYCOMING TIO-540-J2BD ENGINE (S/N 890-X) NAFEC TEST DATA--TAKEOFF MODE--(LEAN-OUT RUNS) SPARK SETTING 20° BTC

	Parameter	Run No. / Mode	21 Takeoff	22 Takeoff	23 Takeoff	23 Takeoff
1.	Act. Baro. - inHgA		29.95	29.95	29.95	29.95
2.	Spec. Hum. - lb/lb		0.0030	0.0030	0.0030	0.0030
3.	Induct. Air Temp.-°F		52	52	52	52
4.	Cooling Air Temp.-°F		50	50	50	50
5.	Induct. Air Press.-inHgA		30.05	30.06	30.06	30.07
6.	Engine Speed - RPM		2575	2575	2575	2575
7.	Manifold Air Press.-inHgA		42.7	42.6	42.2	42.0
8.	Induct. Air Density-lb/ft^3		0.0778	0.0778	0.0778	0.0778
9.	Fuel Flow, W_f-lb/h		254.0	244.0	234.0	224.0
10.	Airflow, W_a-lb/h		2505.0	2484.0	2432.0	2424.0
11.	F/A (Measured) = 9 / 10		0.1014	0.0982	0.0962	0.0924
12.	Max. Cht - °F		419	437	454	468
13.	Avg. Cht - °F		397	412	422	435
14.	Min. Cht - °F		380	392	399	411
15.	EGT - °F		1184	1204	1222	1246
16.	Torque, lb-ft		734	740	738	742
17.	Obs. Bhp		360	363	362	364
18.	% CO_2 (Dry)		5.57	6.00	6.38	6.97
19.	% CO (Dry)		14.93	14.15	13.44	12.37
20.	% O_2 (Dry)		0.24	0.24	0.24	0.24
21.	HC-ppm (Wet)		1800	1616	1504	1353
22.	NO_x-ppm (Wet)		25	36	48	69
23.	CO_2-lb/h		236.33	249.3	256.3	273.8
24.	CO-lb/h		403.25	374.1	343.7	309.3
25.	O_2-lb/h		7.40	7.25	7.01	6.28
26.	HC-lb/h		3.05	2.69	2.43	2.15
27.	NO_x-lb/h		0.079	0.112	0.145	0.205
28.	CO-lb/Mode		2.016	1.871	1.718	1.547
29.	HC-lb/Mode		0.015	0.013	0.012	0.011
30.	NO_x-lb/Mode		0.0004	0.0006	0.0007	0.010

TABLE C-15. AVCO LYCOMING TIO-540-J2BD ENGINE (S/N 890-X) NAFEC TEST DATA--TAKEOFF MODE--(LEAN-OUT RUNS) SPARK SETTING 20° BTC

	Parameter	Run No. / Mode	60 Takeoff	61 Takeoff	62 Takeoff	63 Takeoff	64 Takeoff
1.	Act. Baro. - inHgA		30.19	30.19	30.19	30.19	30.18
2.	Spec. Hum. - lb/lb		0.0050	0.0050	0.0050	0.0050	0.0050
3.	Induct. Air Temp.-°F		130	134	136	139	141
4.	Cooling Air Temp.-°F		128	133	136	138	140
5.	Induct. Air Press.-inHgA		30.75	30.74	30.75	30.75	30.75
6.	Engine Speed - RPM		2575	2575	2575	2575	2575
7.	Manifold Air Press.-inHgA		43.4	43.0	42.7	42.5	42.6
8.	Induct. Air Density-lb/ft^3		0.0691	0.0686	0.0684	0.0680	0.0678
9.	Fuel Flow, W_f-lb/h		254.0	244.0	234.0	224.0	214.0
10.	Airflow, W_a-lb/h		2380.0	2308.0	2320.0	2284.0	2290.2
11.	F/A (Measured) = 9 / 10		0.1067	0.1057	0.1009	0.0981	0.0934
12.	Max. Cht - °F		449	459	473	485	499
13.	Avg. Cht - °F		426	436	451	464	479
14.	Min. Cht - °F		406	415	428	442	461
15.	EGT - °F		1147	1159	1182	1201	1228
16.	Torque, lb-ft		680	690	695	702	704
17.	Obs. Bhp		333	338	341	344	345
18.	% CO_2 (Dry)		4.93	5.27	5.71	6.11	6.63
19.	% CO (Dry)		15.69	15.13	14.28	13.54	12.55
20.	% O_2 (Dry)		0.24	0.24	0.24	0.23	0.27
21.	HC-ppm (Wet)		2065	1828	1611	1488	1415
22.	NO_x-ppm (Wet)		16	23	34	46	64
23.	CO_2-lb/h		200.46	205.8	220.9	229.7	245.62
24.	CO-lb/h		405.9	376.0	351.6	324.0	295.8
25.	O_2-lb/h		7.09	6.81	6.75	6.29	7.27
26.	HC-lb/h		3.39	2.90	2.52	2.28	2.13
27.	NO_x-lb/h		0.049	0.068	0.100	0.132	0.180
28.	CO-lb/Mode		2.029	1.880	1.758	1.620	1.479
29.	HC-lb/Mode		0.017	0.014	0.013	0.011	0.011
30.	NO_x-lb/Mode		0.0002	0.0003	0.0005	0.0007	0.0009

TABLE C-16. AVCO LYCOMING TIO-540-J2BD ENGINE (S/N 890-X) NAFEC TEST DATA--TAKEOFF MODE--(LEAN-OUT RUNS) SPARK SETTING 20° BTC

	Parameter	Run No. / Mode	98 Takeoff	99 Takeoff	100 Takeoff	101 Takeoff	102 Takeoff
1.	Act. Baro. - inHgA		30.28	30.28	30.28	30.28	30.27
2.	Spec. Hum. - lb/lb		0.0110	0.0110	0.0110	0.0110	0.0110
3.	Induct. Air Temp.-°F		103	100	98	98	99
4.	Cooling Air Temp.-°F		105	98	97	98	99
5.	Induct. Air Press.-inHgA		30.92	30.94	30.95	30.95	30.95
6.	Engine Speed - RPM		2575	2575	2575	2575	2575
7.	Manifold Air Press.-inHgA		43.2	42.8	42.2	42.4	42.4
8.	Induct. Air Density-lb/ft^3		0.0728	0.0732	0.0735	0.0735	0.0734
9.	Fuel Flow, W_f-lb/h		256.0	246.0	236.0	226.0	216.0
10.	Airflow, W_a-lb/h		2423.0	2359.0	2334.0	2344.0	2322.2
11.	F/A (Measured) = 9 / 10		0.1057	0.1043	0.1011	0.0964	0.0930
12.	Max. Cht - °F		437	443	450	463	478
13.	Avg. Cht - °F		414	418	426	439	456
14.	Min. Cht - °F		393	398	403	420	441
15.	EGT - °F		1158	1171	1187	1215	1242
16.	Torque, lb-ft		682	680	682	695	702
17.	Obs. Bhp		334	333	334	341	344
18.	% CO_2 (Dry)		5.20	5.45	5.80	6.41	7.04
19.	% CO (Dry)		15.44	15.02	14.32	13.28	12.24
20.	% O_2 (Dry)		0.21	0.21	0.20	0.21	0.19
21.	HC-ppm (Wet)		2611	2169	2129	1865	1703
22.	NO_x-ppm (Wet)		17	22	30	45	61
23.	CO_2-lb/h		213.3	215.9	224.7	245.4	262.2
24.	CO-lb/h		403.0	378.6	353.1	323.6	290.1
25.	O_2-lb/h		6.26	6.04	5.64	6.00	5.15
26.	HC-lb/h		4.35	3.50	3.36	2.91	2.59
27.	NO_x-lb/h		0.053	0.066	0.089	0.131	0.173
28.	CO-lb/Mode		2.015	1.893	1.766	1.618	1.451
29.	HC-lb/Mode		0.022	0.017	0.017	0.015	0.013
30.	NO_x-lb/Mode		0.0003	0.0003	0.0004	0.0007	0.0009

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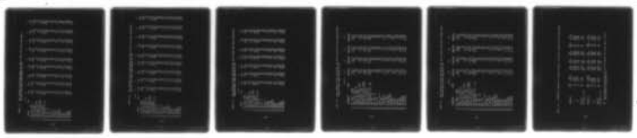

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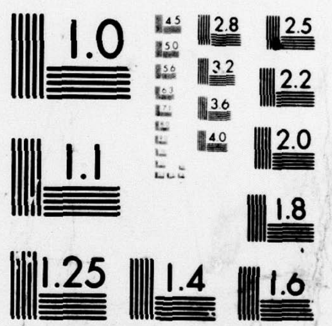

MICROCOPY RESOLUTION TEST CHART
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TABLE C-17. AVCO LYCOMING TIO-540-J2BD ENGINE (S/N 890-X) NAFEC TEST DATA--CLIMB MODE--(NO IDLE, FIVE MODE) SPARK SETTING 20° BTC

	Run No.	12	13	14	15	16	17	18	19	20
Parameter	Mode	Climb	Climb	Climb	Climb	Climb	Climb	Climb	Climb	Climb
1. Act. Baro. - inHgA		29.92	29.92	29.92	29.92	29.92	29.92	29.92	29.92	29.92
2. Spec. Hum. - lb/lb		0.0050	0.0050	0.0050	0.0050	0.0050	0.0050	0.0050	0.0050	0.0060
3. Induct. Air Temp.-°F		50	49	49	50	50	50	50	50	50
4. Cooling Air Temp.-°F		47	47	47	47	47	48	48	48	48
5. Induct. Air Press.-inHgA		30.15	30.15	30.15	30.15	30.16	30.16	30.16	30.16	30.16
6. Engine Speed - RPM		2320	2310	2320	2320	2310	2310	2320	2320	2320
7. Manifold Air Press.-inHgA		37.0	37.0	37.0	37.0	37.0	37.0	37.0	37.0	37.0
8. Induct. Air Density-lb/ft^3		0.0783	0.0785	0.0785	0.0783	0.0784	0.0784	0.0784	0.0784	0.0784
9. Fuel Flow, W_f-lb/h		207.0	197.0	187.0	177.0	167.0	157.0	147.0	137.0	127.0
10. Airflow, W_a-lb/h		1936.0	1952.0	1930.0	1915.0	1918.0	1897.0	1891.0	1883.0	1886.0
11. F/A (Measured) = 9 / 10		0.1069	0.1009	0.0969	0.0924	0.0871	0.0829	0.0777	0.0728	0.0673
12. Max. Cht - °F		335	362	378	394	410	432	449	462	475
13. Avg. Cht - °F		339	345	361	378	392	410	426	439	449
14. Min. Cht - °F		326	329	343	358	372	387	400	411	422
15. EGT - °F		1101	1122	1149	1181	1224	1267	1314	1359	1411
16. Torque, lb-ft		620	642	655	660	665	667	668	670	667
17. Obs. Bhp		274	282	289	292	292	293	295	296	.295
18. % CO_2 (Dry)		5.24	5.76	6.49	7.20	8.15	9.15	10.35	11.62	12.93
19. % CO (Dry)		15.32	14.35	13.02	11.87	10.21	8.51	6.47	4.21	2.11
20. % O_2 (Dry)		0.25	0.25.	0.23	0.24	0.23	0.22	0.22	0.21	0.25
21. HC-ppm (Wet)		2522	2049	1744	1536	1306	1115	936	748	608
22. NO_x-ppm (Wet)		15	27	48	69	123	213	413	944	1806
23. CO_2-lb/h		172.63	187.9	204.4	220.8	244.0	265.5	289.4	316.7	346.5
24. CO-lb/h		321.2	297.9	260.9	231.7	194.5	156.6	115.7	73.0	36.0
25. O_2-lb/h		5.99	5.93	5.27	5.35	5.00	4.62	4.50	4.16	4.87
26. HC-lb/h		3.37	2.71	2.24	1.93	1.61	1.34	1.10	0.860	0.684
27. NO_x-lb/h		0.038	0.067	0.116	0.169	0.284	0.479	0.909	2.03	3.80
28. CO-lb/Mode		26.770	24.822	21.744	19.305	16.209	13.048	9.642	6.086	2.999
29. HC-lb/Mode		0.281	0.226	0.187	0.161	0.134	0.112	0.092	0.072	0.057
30. NO_x-lb/Mode		0.0031	0.0056	0.0096	0.0141	0.0237	0.0399	0.0757	0.169	0.317

TABLE C-18. AVCO LYCOMING TIO-540-J2BD ENGINE (S/N 890-X) NAFEC TEST DATA--CLIMB MODE--
(NO IDLE, FIVE MODE) SPARK SETTING 20° BTC

	Run No.	84	85	86	87	88	89	90	91	92
Parameter	Mode	Climb	Climb	Climb	Climb	Climb	Climb	Climb	Climb	Climb
1. Act. Baro. - inHgA		30.37	30.37	30.37	30.37	30.37	30.37	30.37	30.37	30.36
2. Spec. Hum. - lb/lb		0.0090	0.0090	0.0090	0.0090	0.0090	0.0090	0.0090	0.0090	0.0085
3. Induct. Air Temp.-°F		93	94	94	93	93	94	94	92	93
4. Cooling Air Temp.-°F		92	94	93	92	93	94	93	91	93
5. Induct. Air Press.-inHgA		31.13	31.14	31.15	31.14	31.15	31.14	31.15	31.15	31.14
6. Engine Speed - RPM		2315	2310	2310	2310	2305	2305	2305	2305	2305
7. Manifold Air Press.-inHgA		37.0	37.0	37.0	37.0	37.0	37.0	37.0	37.0	37.0
8. Induct. Air Density-lb/ft^3		0.0746	0.0745	0.0745	0.0746	0.0747	0.0745	0.0745	0.0748	0.0746
9. Fuel Flow, W_f-lb/h		205.0	195.0	183.0	174.0	164.0	154.0	144.0	134.0	123.0
10. Airflow, W_a-lb/h		1915.0	1875.0	1901.0	1877.0	1865.0	1849.0	1849.0	1826.0	1824.0
11. F/A (Measured) = 9 / 10		0.1070	0.1040	0.0963	0.0927	0.0879	0.0833	0.0779	0.0734	0.0674
12. Max. Cht - °F		375	384	406	418	434	459	467	476	481
13. Avg. Cht - °F		357	365	388	399	414	432	448	456	468
14. Min. Cht - °F		344	352	373	385	401	416	430	441	456
15. EGT - °F		1085	1103	1140	1165	1203	1241	1292	1328	1378
16. Torque, lb-ft		600	605	623	631	638	642	645	645	635
17. Obs. Bhp		265	266	274	278	280	282	283	283	279
18. % CO_2 (Dry)		5.13	5.55	6.32	6.93	7.91	8.86	10.28	11.31	13.07
19. % CO (Dry)		15.57	14.71	13.27	12.18	10.61	9.00	6.60	5.01	2.33
20. % O_2 (Dry)		0.25	0.24	0.24	0.23	0.22	0.21	0.20	0.21	0.21
21. HC-ppm (Wet)		2879	2430	2025	1796	1559	1280	1206	864	656
22. NO_x-ppm (Wet)		13	21	39	60	104	174	390	679	1773
23. CO_2-lb/h		167.3	174.2	196.4	208.4	230.9	250.4	281.5	300.7	338.9
24. CO-lb/h		321.2	293.9	262.5	233.1	197.1	161.9	115.0	84.8	38.4
25. O_2-lb/h		5.93	5.48	5.42	5.03	4.67	4.31	3.98	4.06	3.96
26. HC-lb/h		3.81	3.12	2.56	2.21	1.88	1.50	1.18	0.970	0.714
27. NO_x-lb/h		0.032	0.050	0.092	0.138	0.234	0.382	0.839	1.42	3.61
28. CO-lb/Mode		26.935	24.495	21.874	19.425	16.426	13.490	9.587	7.065	3.204
29. HC-lb/Mode		0.318	0.260	0.213	0.184	0.156	0.125	0.098	0.080	0.059
30. NO_x-lb/Mode		0.0027	0.0042	0.0077	0.0115	0.0195	0.0319	0.0699	0.118	0.301

TABLE C-19. AVCO LYCOMING TIO-540-J2BD ENGINE (S/N 890-X) NAFEC TEST DATA--CLIMB MODE--(LEAN-OUT RUNS) SPARK SETTING 20° BTC

Parameter	Run No.	46	47	48	49	50	51	52
	Mode	Climb	Climb	Climb	Climb	Climb	Climb	Climb
1. Act. Baro. - inHgA		30.14	30.14	30.14	30.14	30.14	30.14	30.12
2. Spec. Hum. - lb/lb		0.0060	0.0060	0.0060	0.0060	0.0060	0.0060	0.0060
3. Induct. Air Temp.-°F		131	134	130	132	134	130	134
4. Cooling Air Temp.-°F		132	134	127	132	134	127	135
5. Induct. Air Press.-inHgA		30.42	30.42	30.43	30.43	30.44	30.46	30.82
6. Engine Speed - RPM		2310	2310	2305	2310	2300	2310	2300
7. Manifold Air Press.-inHgA		37.0	36.9	37.0	36.8	37.1	37.0	37.0
8. Induct. Air Density-lb/ft^3		0.0682	0.0679	0.0684	0.0681	0.0679	0.0684	0.0688
9. Fuel Flow, W_f-lb/h		194.0	184.0	174.0	164.0	154.0	144.0	134.0
10. Airflow, W_a-lb/h		1769.0	1765.0	1746.0	1745.0	1745.0	1720.0	1699.0
11. F/A (Measured) = 9 / 10		0.1097	0.1042	0.0997	0.0940	0.0883	0.0837	0.0789
12. Max. Cht - °F		405	422	435	448	471	495	494
13. Avg. Cht - °F		386	402	414	427	451	466	477
14. Min. Cht - °F		376	389	399	410	433	443	460
15. EGT - °F		1087	1110	1137	1166	1210	1253	1280
16. Torque, lb-ft		570	576	590	590	600	600	595
17. Obs. Bhp		251	253	259	260	263	264	261
18. % CO_2 (Dry)		5.08	5.56	6.20	6.84	8.02	9.13	10.21
19. % CO (Dry)		16.43	15.45	14.18	13.06	11.09	9.08	7.20
20. % O_2 (Dry)		0.26	0.27	0.25	0.26	0.24	0.24	0.26
21. HC-ppm (Wet)		2677	2238	1923	1721	1398	1174	1065
22. NO_x-ppm (Wet)		15	26	43	63	124	230	418
23. CO_2-lb/h		156.7	167.5	181.1	195.7	222.2	242.1	260.8
24. CO-lb/h		322.5	296.2	263.6	237.8	195.6	153.2	117.1
25. O_2-lb/h		5.61	5.91	5.31	5.41	4.84	4.63	3.83
26. HC-lb/h		3.30	2.70	2.26	1.98	1.58	1.28	1.13
27. NO_x-lb/h		0.035	0.059	0.095	0.136	0.262	0.471	0.830
28. CO-lb/Mode		26.877	24.969	21.874	19.814	16.296	12.768	9.756
29. HC-lb/Mode		0.275	0.225	0.188	0.165	0.131	0.107	0.094
30. NO_x-lb/Mode		0.0029	0.0049	0.0079	0.0113	0.0218	0.0392	0.0692

TABLE C-20. AVCO LYCOMING TIO-540-J2BD ENGINE (S/N 890-X) NAFEC TEST DATA--APPROACH MODE--(LEAN-OUT RUNS) SPARK SETTING 20° BTC

	Run No.	42	43	44	45
Parameter	**Mode**	**Approach**	**Approach**	**Approach**	**Approach**
1. Act. Baro. - inHgA		30.15	30.15	30.15	30.14
2. Spec. Hum. - lb/lb		0.0055	0.0055	0.0055	0.0055
3. Induct. Air Temp.-°F		128	130	133	131
4. Cooling Air Temp.-°F		128	132	136	131
5. Induct. Air Press.-inHgA		30.55	30.55	30.54	30.54
6. Engine Speed - RPM		2225	2230	2240	2240
7. Manifold Air Press.-inHgA		21.9	21.7	21.8	21.7
8. Induct. Air Density-lb/ft^3		0.0689	0.0686	0.0683	0.0685
9. Fuel Flow, W_f-lb/h		94.5	84.5	74.5	64.5
10. Airflow, W_a-lb/h		1041.0	1017.0	1015.0	994.0
11. F/A (Measured) = 9 / 10		0.0908	0.0831	0.0734	0.0649
12. Max. Cht - °F		367	384	401	410
13. Avg. Cht - °F		352	369	390	396
14. Min. Cht - °F		337	351	370	381
15. EGT - °F		1050	1101	1172	1234
16. Torque, lb-ft		328	325	330	318
17. Obs. Bhp		139	138	141	136
18. % CO_2 (Dry)		7.27	8.91	11.17	13.07
19. % CO (Dry)		12.29	9.33	5.47	2.21
20. % O_2 (Dry)		0.32	0.31	0.30	0.54
21. HC-ppm (Wet)		2010	1614	1171	660
22. NO_x-ppm (Wet)		96	237	860	1847
23. CO_2-lb/h		122.8	140.2	166.9	185.7
24. CO-lb/h		132.1	93.4	52.0	20.0
25. O_2-lb/h		3.93	3.55	3.26	5.58
26. HC-lb/h		1.36	1.04	0.73	0.39
27. NO_x-lb/h		0.122	0.286	0.999	2.04
28. CO-lb/Mode		13.213	9.344	5.201	1.998
29. HC-lb/Mode		0.136	0.104	0.073	0.039
30. NO_x-lb/Mode		0.0122	0.0286	0.0999	0.0204

TABLE C-21. AVCO LYCOMING TIO-540-J2BD ENGINE (S/N 890-X) NAFEC TEST DATA--APPROACH MODE--(LEAN-OUT RUNS) SPARK SETTING 20° BTC

	Parameter	MODE / Run No.	80 Approach	81 Approach	82 Approach	83 Approach
1.	Act. Baro. - inHgA		30.37	30.37	30.35	30.37
2.	Spec. Hum. - lb/lb		0.0085	0.0085	0.0085	0.0085
3.	Induct. Air Temp.-°F		92	91	93	96
4.	Cooling Air Temp.-°F		90	89	92	98
5.	Induct. Air Press.-inHgA		31.27	31.28	31.31	31.28
6.	Engine Speed - RPM		2230	2235	2235	2235
7.	Manifold Air Press.-inHgA		21.6	21.5	21.75	21.9
8.	Induct. Air Density-lb/ft^3		0.0751	0.0752	0.0750	0.0746
9.	Fuel Flow, W_f-lb/h		95.0	85.0	75.0	65.0
10.	Airflow, W_a-lb/h		1064.0	1088.0	1063.0	1061.0
11.	F/A (Measured) = 9 / 10		0.0893	0.0781	0.0706	0.0613
12.	Max. Cht - °F		341	357	379	385
13.	Avg. Cht - °F		328	343	365	364
14.	Min. Cht - °F		317	331	351	344
15.	EGT - °F		1070	1125	1187	1265
16.	Torque, lb-ft		338	346	342	326
17.	Obs. Bhp		144	147	146	139
18.	% CO_2 (Dry)		7.84	9.86	11.75	13.76
19.	% CO (Dry)		10.81	7.38	4.10	0.24
20.	% O_2 (Dry)		0.27	0.27	0.27	0.95
21.	HC-ppm (Wet)		1928	1453	1135	265
22.	NO_x-ppm (Wet)		112	333	1033	2300
23.	CO_2-lb/h		129.8	160.8	180.3	203.9
24.	CO-lb/h		113.9	76.6	40.0	2.26
25.	O_2-lb/h		3.25	3.20	3.01	10.24
26.	HC-lb/h		1.33	0.985	0.731	0.167
27.	NO_x-lb/h		0.145	0.423	1.244	2.708
28.	CO-lb/Mode		11.392	7.660	4.005	0.226
29.	HC-lb/Mode		0.133	0.099	0.0731	0.0167
30.	NO_x-lb/Mode		0.0145	0.0423	0.1244	0.2708

TABLE C-22. ARITHEMATIC AVERAGING OF BASELINE (TABLE 5) DATA--AVCO LYCOMING TIO-540-J2BD ENGINE

Baseline No.	Avg. T_i-°F	Avg. ρ_i-lb/ft^3	CO lb/Cyc.	HC lb/Cyc.	NO_x lb/Cyc.	MAX. CHT-°F	Avg. Cyc. F/A
1	74	0.0744	49.076	1.413	0.0182	411	0.1028
2	62	0.0775	50.204	1.113	0.0199	409	0.1002
4	55	0.0778	51.079	0.959	0.0205	421	0.1003
5	63	0.0779	53.151	1.026	0.0168	423	0.1000
11	52	0.0777	52.315	1.118	0.0155	415	0.1028
Total (5)	306	0.3853	255.825	5.629	0.0909	2079	0.5061
Avg. of 5	61	0.0771	51.165	1.126	0.0182	416	0.1012
Avg. Emiss.-% of STD			348.1	169.3	3.5		

Baseline No.	Avg. T_i-°F	Avg. ρ_i-lb/ft^3	CO lb/Cyc.	HC lb/Cyc.	NO_x lb/Cyc.	MAX. CHT-°F	Avg. Cyc. F/A
7	119	0.0694	50.748	1.644	0.0168	457	0.1036
8	115	0.0703	49.322	1.234	0.0172	453	0.1030
9	96	0.0731	55.751	1.399	0.0041	432	0.1023
10	95	0.0728	50.628	1.748	0.0124	436	0.1061
Total (4)	425	0.2856	206.449	6.025	0.0405	1778	0.4150
Avg. of 4	106	0.0714	51.612	1.506	0.0101	444	0.1038
Avg. Emiss.-% of STD			351.1	226.5	1.9		

NOTE: The data presented above was grouped for arithematic averaging so that two basic ambient conditions could be evaluated on a generalized basis.